

THE DEVELOPMENT OF A METHOD  
FOR THE DETERMINATION OF ACOUSTIC  
CHARACTERISTICS OF VENTILATING FANS

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JOHN L. REYNOLDS  
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OF ACOUSTIC CHARACTERISTICS OF VENTILATING FANS

by

John L. Reynolds, Lieutenant (junior grade), U.S. Navy.  
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Kenneth E. Wilson, Jr., Lieutenant (junior grade), U.S. Navy.  
B.S., U.S. Naval Academy, 1946.

Submitted in Partial Fulfillment  
of the Requirements for the  
Degree of Naval Engineer  
from the  
Massachusetts Institute of Technology  
1952

Authors

Department of Naval Architecture and Marine Engineering

May 16, 1952



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The primary object of this series of tests was  
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In the process of this development, it was hoped that  
information could be obtained which would make it possible  
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CHARACTERISTICS BY VISUALIZATION TECHNIQUE

Author:-

John L. Hayward, Lieutenant (Junior Grade), U.S. Navy,  
U.S. Naval Academy, 1946.  
Kenneth H. Wilson, Jr., Lieutenant (Junior Grade), U.S. Navy,  
U.S. Naval Academy, 1946.Submitted in partial fulfillment of the requirements for the  
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Two fans of different capacities (500 and 1500 cfm)

were tested at various speeds and at various moisture back  
pressures. The test setup consisted of a duct system of heavy  
construction into which the fan noise was directed. The duct

was terminated in an exponential horn to prevent acoustic reflections and standing waves in the measuring duct. Absolute sound-pressure level was measured in the duct using a miniature condenser microphone inserted therein and shielded by a windscreen. The output of the microphone was amplified and measured directly on a vacuum-tube voltmeter for overall levels. The noise spectra for the different conditions of speed and back pressure were obtained using a one-third octave-band filter set with band-center frequencies between 100 and 10,000 cps.

The data obtained for the smaller of the two fans indicated high sound-pressure levels in the frequency bands containing the fundamental and fourth harmonic of the blade frequency. As frequency increased, a general trend toward lower spectrum levels was observed. The same general trends were found to exist in the spectra of the larger fan; but, probably due to compressibility effects, the fundamental and harmonic peaks were not clearly observable. From the data for overall sound-pressure level, a formula was derived that gave power levels in close agreement with those measured for both fans above a speed of about 2600 RPM.

The consistency of data and conformity with theory were used as a basis for determining the adequacy of this new test method. The general agreement of trends

was determined in an experimental point to present acoustic  
 reflections and standing waves in the resonating duct.  
 The acoustic pressure level was measured in the duct  
 using a miniature condenser microphone connected through  
 and insulated by a windshield. The output of the micro-  
 phone was amplified and measured directly on a vacuum-  
 tube voltmeter for steady signals. The noise spectra  
 for the different conditions of speed and back pressure  
 were measured using a one-third octave-band filter and  
 with band-center frequencies between 100 and 10,000 cps.

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two indicated high sound-pressure levels in the frequency  
 bands containing the fundamental and fourth harmonics of  
 the blade frequency. In frequency intervals, a general  
 trend toward lower spectrum levels was observed. The  
 same general trends were found to exist in the spectra  
 of the larger test bed. Probably due to compressibility  
 effects, the fundamental and harmonic levels were not  
 equally dominant. From the data for overall sound-power  
 level, a formula was derived that gave power levels  
 in close agreement with those measured for both test beds  
 at speeds of about 500 rpm.

The consistency of data and agreement with

theory was used as a basis for determining the adequacy  
 of this test method. The general agreement of trends

among all data taken, some agreement with axial-flow compressor theory, and satisfactory repeatability of data all indicated that the method is adequate to accomplish its proposed function. The satisfactory conformity of measured with computed overall power levels indicated that the empirical formula derived is of correct form.

Further work is essential in connection with the ventilating system source analysis. This work should include tests of axial-flow fans of other sizes and designs to substantiate or correct the findings of this investigation.

Thesis Supervisor:-

Leo L. Beranek

Title:-

Associate Professor  
Electrical Engineering



Cambridge, Massachusetts

May 16, 1952

Secretary of the Faculty  
Massachusetts Institute of Technology  
Cambridge, Massachusetts

Dear Sir:-

In accordance with the requirements for the  
Degree of Naval Engineer, we submit a thesis entitled:-  
"The Development of a Method for the Determination of  
Acoustic Characteristics of Ventilating Fans".

Respectfully yours,

John B. Reynolds,  
Lieutenant (junior grade),

Benjamin E. Wilson, Jr.  
Lieutenant (junior grade),  
U. S. Navy



ACKNOWLEDGEMENTS

The authors wish to acknowledge their indebtedness to Professor Leo L. Beranek, Technical Director of the Acoustics Laboratory, Massachusetts Institute of Technology, for his continual help and criticism in the course of this investigation. We also thank Mr. Henry C. Lang for his advice in all phases of the work, Mr. George Kamperman for invaluable assistance in setting up the measuring system, and Miss Lydia Bonazzoli for the accomplishment of many little things throughout this study, and her typing of this final report. Finally, we thank everyone connected with the Acoustics Laboratory for his patience and help, without which the completion of this investigation would have been impossible.

WITNESSES

The witness also is acknowledged their indebtedness to Professor J. L. Hayward, Technical Director of the Scientific Laboratory, Massachusetts Institute of Technology, for his continual help and advice in the course of this investigation. He also thank Mr. Henry C. Lang for his advice in all phases of the work. Dr. George Raymond for valuable assistance in setting up the recording system, and Miss Lillian Cummings for the acknowledgment of many little things throughout this study, and her typing of this final report. Finally, we thank everyone connected with the Houston Laboratory for his assistance and help, without which the completion of this investigation would have been impossible.

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## I. INTRODUCTION

Aboard ship, in office buildings, and in industrial plants, one of the important sources of noise is the ventilating system. If complete acoustic characteristics of these systems are determined, it is possible to make accurate predictions of noise levels in spaces supplied by these systems. Design engineers can then design the duct system mechanically and acoustically to attain a specified noise level in the ventilated spaces.

This study was the first step in a proposed acoustical analysis of ventilating systems. The ventilating system analysis will be divided into a study of fans, duct systems, and duct terminations. This investigation pertains to the first phase of the problem, the determination of the characteristics of axial-flow fans as acoustic power sources.

It was the specific purpose of this investigation to determine the adequacy of a proposed method for obtaining the acoustic characteristics of ventilating fans. The major consideration was the quality of the data obtained using the proposed test set-up. The quality of the data was judged by comparing the data obtained for the fans tested, under varying conditions of speed and back pressure.

## 1. INTRODUCTION

board ship, in other buildings, and in other  
places, one of the important sources of noise is  
the ventilating system. It is possible to obtain  
information of these systems and determine, if it is possible  
to make accurate predictions of noise levels in spaces  
served by these systems. Design engineers can then  
design the duct system acoustically and economically  
to obtain a specified noise level in the conditioned spaces.

This study was the first step in a proposed  
systematic analysis of ventilating systems. The ventil-  
ating system analysis will be divided into a study of  
duct, duct system, and duct termination. This investi-  
gation pertains to the first phase of the problem. The  
determination of the characteristics of air-flow from  
an acoustic power source.

It was the specific purpose of this investigation  
to determine the accuracy of a proposed method for obtaining  
the acoustic characteristics of ventilating ducts. The  
major consideration was the quality of the data obtained  
using the proposed test set-up. The quality of the data  
was judged in comparing the data obtained for the test  
cases, under varying conditions of speed and duct geometry.

The method presently used by the Navy of testing ventilating fans is felt to be somewhat limited in its scope and in the application of the data which can be obtained. This method, now in use at the Material Laboratory, New York Naval Shipyard, consists of sound measurements around the fan casing for varying conditions of back pressure and at constant speed. The measurements are made in an acoustically treated room (not an anechoic chamber), the acoustic qualities of which would be difficult or impossible to duplicate. No information is obtained on the frequency spectrum of the fan, and the noise transmitted down a duct cannot be determined. Therefore, these data cannot be used to assist in the prediction of noise levels in spaces supplied by a duct system. Its only value lies in making possible the intercomparison of various fans of the same type.

The proposed method for determining the sound-power output of a ventilating fan consisted, basically, of measuring the sound-power level in a duct connected to the fan exhaust. Reflections and standing waves are prevented in the measuring duct by terminating the duct in an exponential horn.

Various tests were made to determine the adequacy of the experimental duct system. It was found that sound-

The method previously used up the way of testing

ventilating fans is that it is somewhat limited in its

scope and in the application of the data which can be

obtained. This method, used in one of the National Bureau-

of Standards tests, was used by the Navy Bureau of Naval Weapons-

to determine the fan casing for testing conditions is

best obtained and at constant speed. The measurements

are made in an acoustically treated room just as possible

possible. The acoustic qualities of noise would be different

at different fan speeds. An important factor is obtained

on the frequency spectrum of the fan, and the noise level

is then a good basis for determining the noise level.

Data cannot be used to assist in the prediction of noise

level in space supplied by a fan system. The only

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The proposed method for determining the sound-

power output of a ventilating fan operating, basically,

of measuring the sound-power level in a duct connected

to the fan exhaust. Reflections and standing waves are

prevented in the measuring duct by terminating the duct

in an anechoic room.

Further tests were made to determine the adequacy

of the experimental test system. It was found that sound-

pressure levels remained essentially constant as the microphone was moved axially in the duct, although the sound-pressure level was changed by radial movement of the microphone in the measuring duct. A windscreen was placed around the microphone in all tests to minimize the effect of wind noise on measured sound-pressure levels.

Two fans of different capacities were tested in this investigation. At various speeds and back pressures, frequency spectrum and overall sound-pressure levels were recorded. These data were studied to determine the appearance of high levels at the blade frequency fundamental and its harmonics. The overall levels for the two fans were compared, and an empirical formula was derived whereby overall power level could be predicted for a given fan operating at a certain speed.

The data obtained was consistent, and it was believed to be of a type which will be of value to the design engineer. Trends followed those expected in most cases, and the data compared favorably with results of tests for noise levels produced by airplane propellers. It is therefore felt that the proposed test method is a good one, and it warrants further investigation and exploitation.

however level is assumed constant at the  
altitude was used only in the first, although the  
normal pressure level was changed by several percent of  
the atmosphere in the remaining cases. A standard was  
placed around the atmosphere in all cases as indicated  
the effect of which was to remove some pressure levels.

The case of different altitudes was tested  
in this investigation. At various speeds and bank pro-  
cesses, different altitudes and several wind directions  
levels were considered. These data were similar to data  
from the appearance of high levels at the blade frequency  
fundamental and its harmonics. The overall level for  
the first two were compared, and an adjusted level was  
derived which overall power level would be predicted  
for a given two quantities at a certain speed.

The data obtained was compared, and it was  
believed to be of a type which will be of value to the  
design engineer. Results followed those reported in our  
cases, and the data compared favorably with results of  
other low noise levels produced by airplane propellers.  
It is therefore felt that the proposed test method is  
a good one, and it warrants further investigation and  
application.

## II. PROCEDURE

Since the purpose of this thesis is to determine an adequate and meaningful method of obtaining the sound-power output of ventilating fans, much time was spent in arriving at the method of testing the fans and in setting up the apparatus and equipment to be used in the fan tests. It thus seems fitting that the equipment and the test method employed should be described in detail.

### A. Test Setup

#### 1. Duct System (Fig. 1)

a. Measuring Duct - It was decided that sound-pressure level measurements should be made by placing a microphone in a duct which extended from the exhaust end of the fan. Measurements were to be made at a point about 8 feet from the fan. Since it was planned to test three fans, the  $A\frac{1}{2}$ ,  $Al\frac{1}{2}$ , and  $A3$ , the duct was designed with the same inside diameter as that of the largest fan, that is,  $21\frac{1}{8}$  inches. This duct was 5 feet in length, of circular cross-section, and of  $\frac{1}{16}$ -inch galvanized steel construction. In testing the two smaller fans, three-foot circular sections of

## II. Procedure

Since the purpose of this study is to

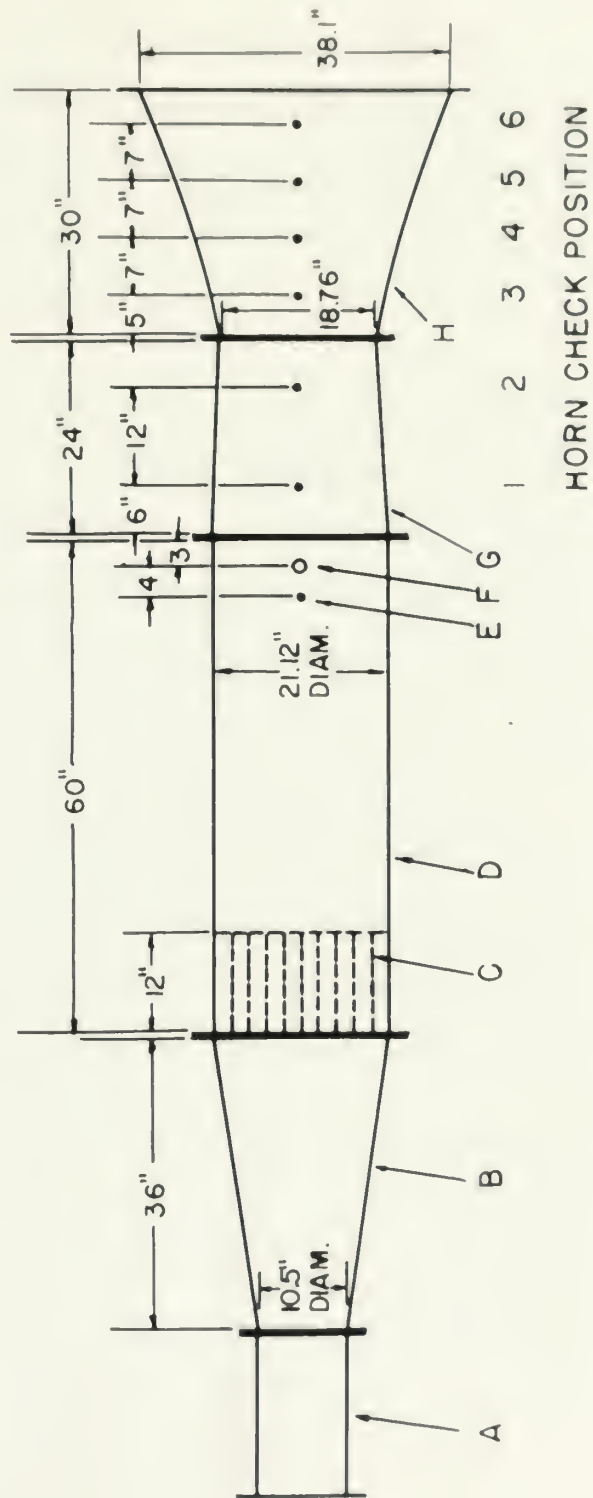
determine an accurate and reliable method of  
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### A. Test Setup

#### 1. Test System (Fig. 1)

A. Sounding Board - It was decided that  
sound-pressure level measurements should be made by  
placing a microphone in a duct which extended from the  
exhaust end of the fan. Measurements were to be made  
at a point about 5 feet from the fan. Since it was  
planned to test three fans, the  $\frac{1}{2}$ ,  $\frac{1}{4}$ , and  $\frac{1}{8}$  hp  
fans were designed with the same inside diameter as that  
of the largest fan, that is,  $11\frac{1}{2}$  inches. This duct  
was 2 feet in length, of elliptical cross-section, and  
of  $\frac{1}{16}$ -inch galvanized steel construction. In testing  
the two smaller fans, three-foot elliptical sections of

- |                        |                       |
|------------------------|-----------------------|
| A- FAN A $\frac{1}{2}$ | E- MANOMETER FIXTURE  |
| B- EXPANSION SECTION   | F- MICROPHONE OPENING |
| C- STRAIGHTENING VANES | G- ADAPTER            |
| D- MEASURING SECTION   | H- EXPONENTIAL HORN   |



FAN AND DUCT SYSTEM

FIGURE 1



increasing area were placed between the fans and the five-foot measuring duct. Nine straightening vanes were inserted in the duct about 4 feet from the fan in order to reduce the turbulence of air flow. A manometer connection and microphone opening were placed in the measuring duct as shown in Fig. 1.

b. Exponential Horn - In order to prevent wave reflections and resulting standing waves, an exponential horn was placed at the end of the measuring duct. This horn appeared acoustically to the fans and duct as an extending duct of infinite length.<sup>1 \*</sup> It was decided that the horn could be constructed most conveniently with a square cross-section and using  $\frac{1}{4}$ -inch plywood. The square exponential section used in the horn made it necessary to insert a two-foot, steel circular-to-square cross-section adapter between the measuring duct and the horn. The adapter was designed with constant cross-section area.

c. Damping - In order to reduce induced vibrations in the duct, the outside of the entire system was coated with about  $\frac{3}{16}$  inch of Komul, a standard Navy preservative, which has a tar-like consistency and color. It was readily observable that the application of the Komul damped the system considerably.

-----

interconnecting tubes were placed between the tank and the  
 100-1000 watt heater unit. Nine interconnecting tubes  
 were inserted in the duct about 4 feet from the fan in  
 order to reduce the turbulence of air flow. A secondary  
 connection and nitrogenous opening were placed in the  
 measuring duct as shown in Fig. 1.

2. Exponential Horn - In order to prevent  
 wave reflections and resulting standing waves, an exponen-  
 tial horn was placed at the end of the measuring duct.  
 This horn appeared acoustically to the tank and duct  
 as an extending duct of infinite length. It was designed  
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 a square cross-section and using  $\frac{1}{4}$ -inch plywood. The  
 square exponential section used in the horn made it neces-  
 sary to insert a two-foot, steel circular-to-square cross-  
 section adapter between the measuring duct and the horn.  
 The adapter was designed with constant cross-section area.

3. Damping - In order to reduce induced  
 vibrations in the duct, the outside of the entire system  
 was coated with about  $\frac{1}{2}$  inch of foam, a standard heavy  
 preservative, which has a low-loss conductivity and color.  
 It was readily observable that the application of the  
 foam damped the system considerably.

## 2. Back Pressure

In order to create back pressure in the measuring ducts, a fine mesh screen, with four layers of cloth attached thereto, was secured firmly over the horn mouth. This arrangement was used during part of the tests, only.

## 3. Fans and Speed Control

Speed control was obtained in both fan tests by placing a variable resistance in the armature circuit of the direct-current motor supplied with the fan. A starting box was placed across the 110-volt d-c supply line.

## 4. Measuring System

The measurements in these tests included measurements of speed, power, back pressure, and sound-pressure level. The speed of the fans was measured by means of a stroboscope. The power input was measured only in the test of the  $Al\frac{1}{2}$  fan, which has a series wound motor. The mechanical power was calculated from measurements of terminal voltage and motor current, using field and armature resistance determined from a blocked rotor test. Simpson meters were used for the electrical measurements. Back pressure was measured by means of a draft gauge manometer connected by a fitting in the top of the duct.

## 2. Basic Principles

In order to obtain back pressure in the measuring device, a line must be connected with four liters of liquid nitrogen. This liquid nitrogen was used during part of the tests, only.

## 3. Flow and Speed Control

Speed control was obtained in both the tests by changing a variable resistance in the electric circuit of the direct-current motor supplied with the fan. A starting box was placed across the 110-volt d-c supply line.

## 4. Measuring System

The measurements in these tests included measurements of speed, power, back pressure, and back pressure level. The speed of the fan was measured by means of a tachometer. The power input was measured only in the test of the  $\frac{1}{2}$  fan, which has a series wound motor. The mechanical power was calculated from measurements of terminal voltage and motor current. Back pressure was measured with a differential pressure transducer connected to a differential amplifier. Back pressure was measured by means of a differential amplifier connected to a sliding in the top of the duct.

The sound measuring system was designed to obtain, as accurately and as simply as possible a measurement of the absolute sound-pressure level referred to  $0.0002 \text{ dyne/cm}^2$ . Overall as well as narrow-band measurements were desired.

Basically, the system consisted of an Altec-Lansing, Model 21-B condenser microphone; Altec-Lansing 40-db line amplifier; a Ballantine Laboratories, 0.001 - 100-volt vacuum-tube voltmeter; and a Telefon one-third octave filter. Each component was calibrated, and from this calibration direct readings of absolute sound-pressure level were determined.\*

The 21-B microphone was chosen because of its small physical dimensions. Being small it was not expected to disturb seriously the sound field in the range of frequencies (100 - 10,000 cps) considered for the test. An effective windscreen with reasonably small dimensions could be fitted around it. Besides having a desirable size and shape, the frequency response was reasonably flat over most of the range considered.\*\*

---

\* Appendix - page A-3

\*\* Appendix - page A-4

The sound measuring system was designed to

obtain, as accurately and as simply as possible a

measurement of the acoustic wave-pressure level refer-

red to 0.001 dyne/cm<sup>2</sup>. This is well as above-mentioned

measurements were designed.

Basically, the system consisted of an elec-

tronic Model 24-A condenser microphone, a 100-ohm

50-ohm resistor, a balanced inductor, 0.001 -

100-ohm variable-capacitor, and a 100-ohm non-induc-

tive filter. Each component was calibrated, and from

this calibration direct readings of acoustic wave-pressure

level were obtained.

The 51-A microphone was chosen because of its

small physical dimensions. Being small it was not expected

to disturb seriously the sound field in the range of

frequencies (100 - 10,000 cps) considered for the test.

An effective wavelength is reasonably small dimensions

would be fitted around it. Besides having a sensitive

size and shape, the frequency response was reasonably

flat over most of the range considered.

\* Appendix - page 4-3

\*\* Appendix - page 4-4

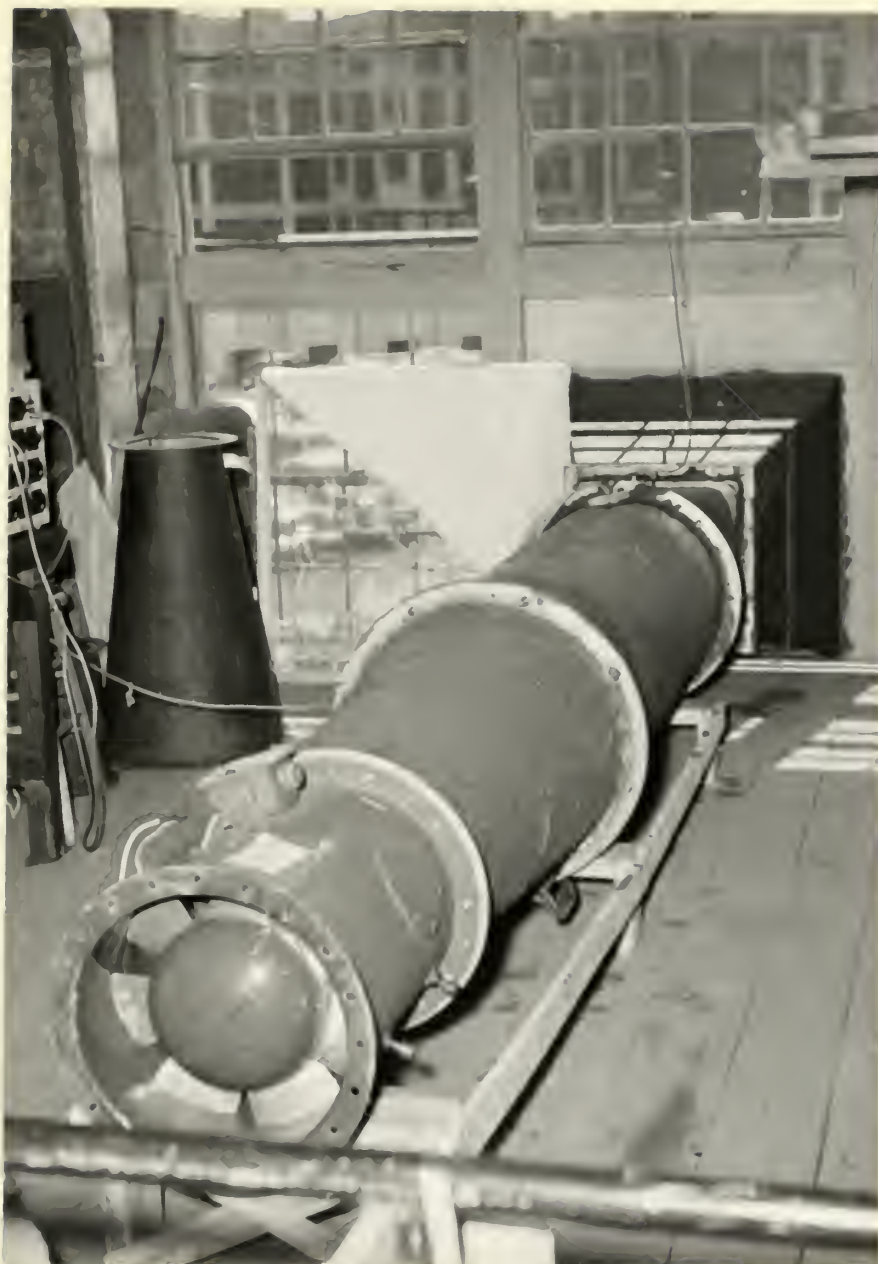


PLATE I

FAN  $A1\frac{1}{2}$  AND DUCT SYSTEM

SHOWING BACK PRESSURE SCREEN AND  $A\frac{1}{2}$  EXPANSION SECTION



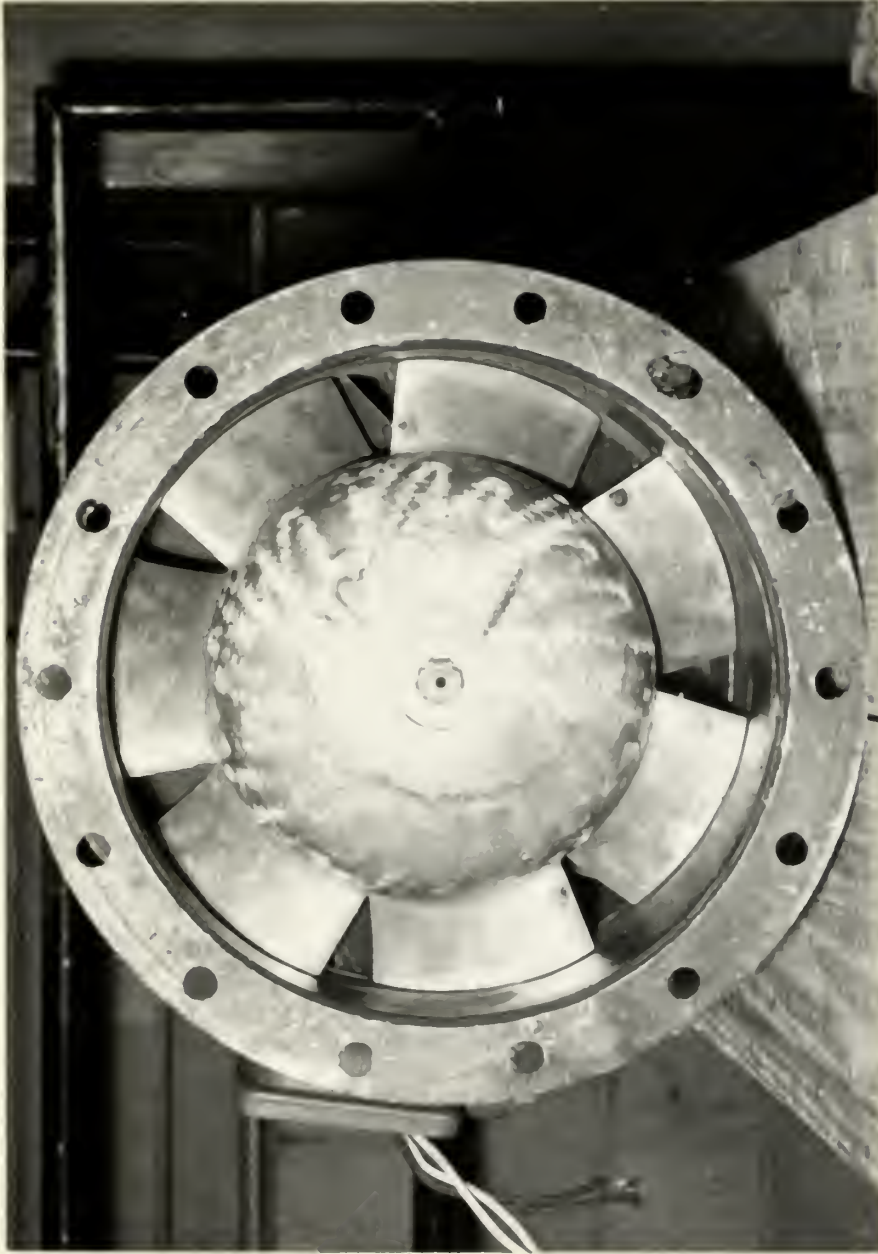


PLATE II

PAN A $\frac{1}{2}$  INTAKE END

THE UNIVERSITY OF CHICAGO

LIBRARY

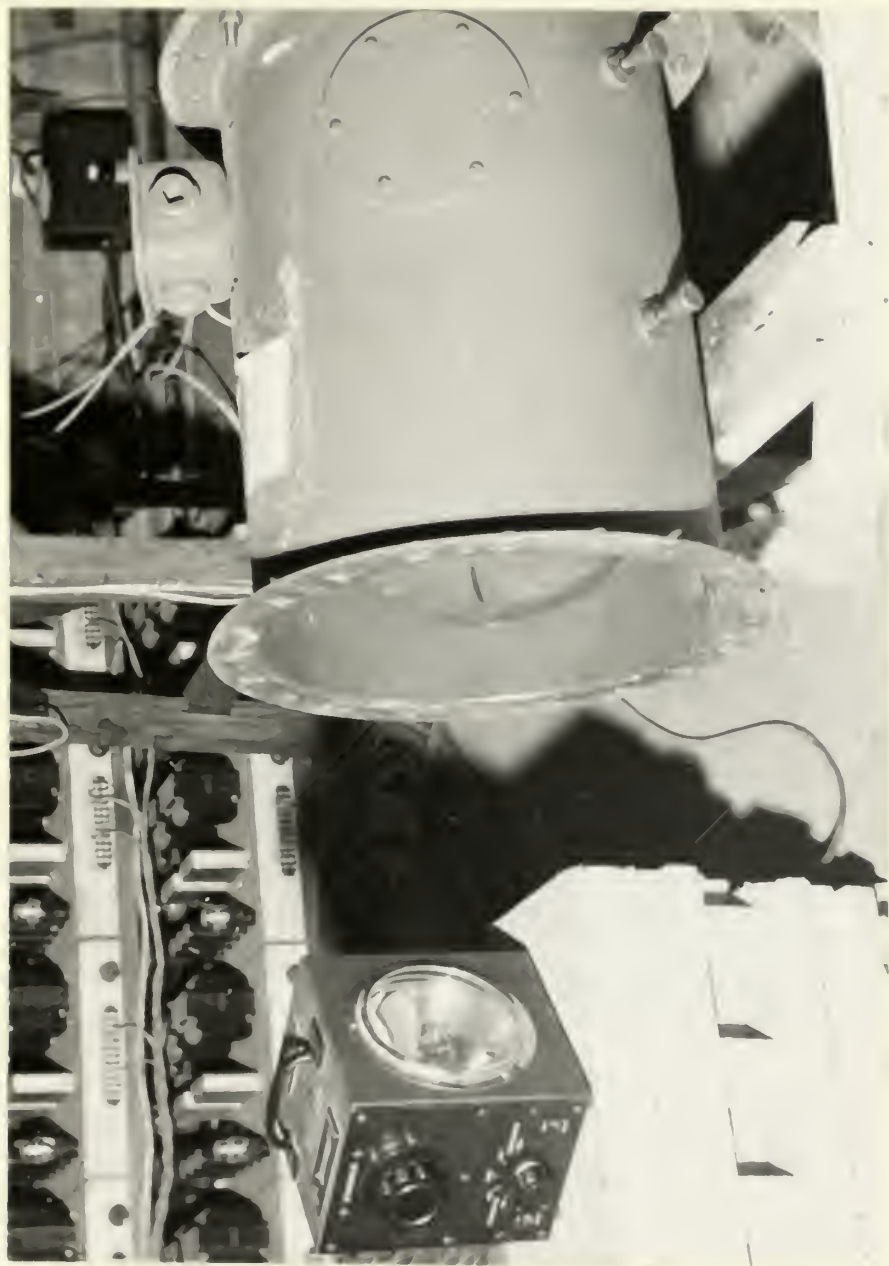


PLATE III

FAN A1 $\frac{1}{2}$  AND STROBOSCOPE

THE L. S. AND S. S. CODE

III STAGE

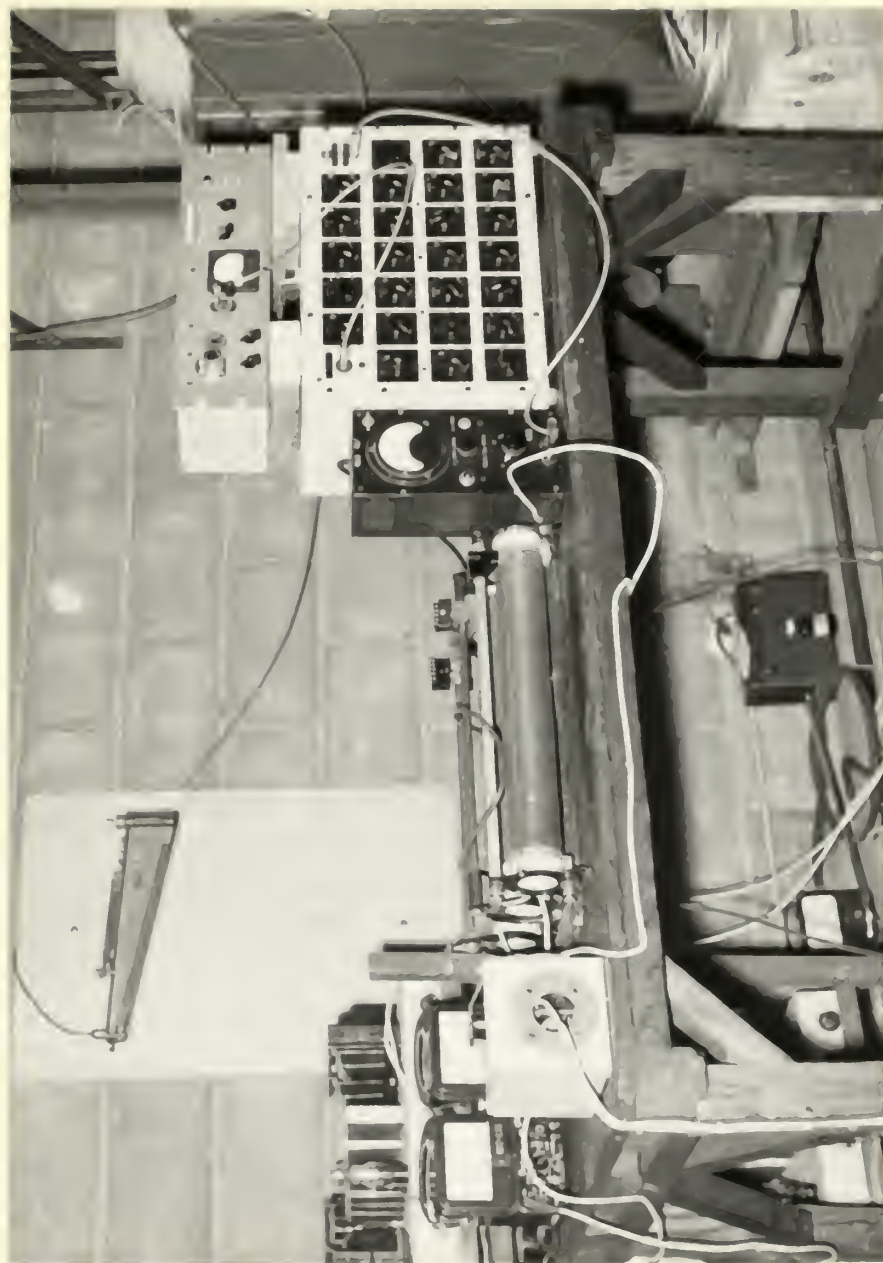


PLATE IV  
FAN SPEED CONTROL AND  
MEASURING INSTRUMENTS





PLATE V

INSIDE OF DUCT SHOWING MICROPHONE  
MICROPHONE WINDSCREEN AND STRAIGHTENING VANES

MISSISSIPPI WINDSHEETS AND STRAIGHTENING TANKS  
INSIDE OF DUTCH SHOWING MISSISSIPPI

PLATE

The Altec-Lansing line amplifier was chosen for its stability as compared with the battery-powered amplifiers used in sound-level meters. Its response is relatively flat over the 100 - 10,000 cps band that was considered. This amplifier also contains the power supply for the vacuum-tube at the base of the Altec, 21-B microphone.

In order to determine the frequency spectra of the fans, the one-third octave filter was inserted between the amplifier and the voltmeter used for the SPL indication. The input impedance adjustment of the filter was set to 10,000 ohms to match the output of the line amplifier.

The filter was checked with an oscillator to ascertain the band shapes, the attenuation to be expected, and the bounding and center frequencies of each band.\*

The Telefon filter has sharply defined pass bands and a flat response between 100 and 10,000 cps. The deviation is small and was neglected for the bands in which it applied.

---

\* Appendix - page A-5

The first-stage line amplifier was chosen for its simplicity in comparison with the design-oriented amplifiers used in other-stage amplifiers. Its frequency response was relatively flat over the 100 - 10,000 cps band that was considered. This amplifier also contains the control simply for the volume-level at the output of the stage. 21-2 microphone.

In order to determine the frequency response of the filter, the gain-bandwidth filter was inserted between the amplifier and the voltmeter used for the SWR calibration. The input impedance adjustment of the filter was set to 10,000 ohms to match the output of the line amplifier.

The filter was checked with an oscilloscope to determine the band shape. The attenuation of the response, and the frequency and center frequencies of each band.

The filter filter was sharply defined pass bands and a flat response between 100 and 10,000 cps. The deviation is small and was neglected for the bands in which it applied.

The "range of accuracy" of the measurements, mentioned above, was controlled primarily by the noise conditions around the Acoustics Laboratory. The accuracy of the equipment and calibration was better than the estimated accuracy of  $\pm 1$  db which resulted from reading fluctuations. There were large fluctuations in overall SPL and in spectrum measurements below about 1000 cps, but the measurements in the upper range of the spectrum were quite steady. Since the sound field conditions set a limit of precision of about  $\pm 1$  db, the small deviations from flat response in the filter and the microphone should not cause the limits in accuracy to be greater than  $\pm 2$  db.

#### B. Test Procedure

After the first fan, duct system, and measuring equipment were readied for the experiment, data were recorded to insure the adequacy of the horn in preventing standing waves in the measuring duct. Neglecting the horn-wall losses, the sound power passing through the duct is constant. The decrease in intensity level, as the microphone was moved out from the horn throat toward the mouth, could be predicted from theory to vary linearly with the axial distance from the horn throat.\*

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\* Appendix - page 31

The "beam of energy" at the measurement  
 position above, was controlled externally by the same  
 conditions around the ionization laboratory. The accuracy  
 of the equipment and calibration was better than the  
 estimated accuracy of  $\pm 1$  to which resulted from testing  
 fluctuations. There were large fluctuations in overall  
 and in spectral measurements below about 1000 eV,  
 but the measurements in the upper range of the spectrum  
 were quite steady. Above the lower limit mentioned  
 and a limit of variation of about  $\pm 1$  to the result  
 deviation from that between in the filter and the  
 absorption should not cause the limit in accuracy is  
 on greater than  $\pm 2$  m.

## 2. Total Spectrum

After the first run, the system, the measuring  
 equipment was tested for the accuracy, this was  
 recorded to insure the accuracy of the data in processing  
 existing data in the laboratory. The following are  
 some of the results, the lower limit being through the  
 limit in constant. The accuracy is relatively large  
 as the microphones were moved not from the same source  
 toward the source. It is predicted that there is very  
 likely with the total spectrum from the same source.

This theoretical variation is plotted as the solid line in Fig. 10, page A-32. Sound-pressure levels were recorded at two axial positions in the adapter and four positions in the horn. Readings were also taken at off-center positions and were found to agree with values along the horn center line. The variation of levels at the various axial positions from the level at the horn throat were also plotted as a function of axial horn position for six fan-operating speeds. Due to fluctuations in the sound-pressure level readings, these values are considered accurate to  $\pm 1.5$  db.

It can be seen from Fig. 10, page A-32, that this  $\pm 1.5$  db region from the theoretical curve includes the majority (80 percent) of the measured points. It was felt that the experiment could be continued with the assurance that the exponential horn was adequately preventing standing waves.

Sound-pressure levels were observed in the measuring section and compared with those taken in the adapter. In this comparison, all readings were made with the microphone on the center line of the duct. At any particular speed, levels at the various axial positions

This horizontal position is shown in the side  
 view in Fig. 10, page 1-12. Sound-pressure levels  
 were measured at two axial positions in the duct  
 and four positions in the horn. Results were also  
 taken at off-center positions and were found to  
 agree with values along the horn center line. The  
 variation of levels at the various axial positions  
 from the level at the horn throat were also plotted  
 as a function of axial horn position for all test-  
 operating speeds. The no-flare horn in the sound-  
 pressure level readings, these values are considered

[illegible][illegible]

agreed to within 2 db. This was considered sufficiently close to the accuracy of any particular reading to justify the assumption that the axial position of the microphone in the duct did not affect the sound-pressure level measurement.

The next test was a determination of the effect of varying the radial position of the microphone in the duct-measuring section. For the  $A_{\frac{1}{2}}$  fan, readings were taken at 3, 6, and 8-inch distances from the duct center for 1000 and 2000 RPM. At the rated speed, levels were recorded at the duct center and at eight other radial positions, spaced 1 inch apart. The frequency spectrum check showed that, at rated speed, no variation in readings occurred below 500 cps and above 4000 cps as the microphone was moved radially outward from the duct center. However, between these frequencies, the sound-pressure level increased as the distance from the duct center was increased. The maximum difference between sound-pressure levels at the duct center and at position eight, 8 inches from the duct center, was 12 db - this difference being noted at about 800 cps. (Fig. 8 - page A-8). At 1000 and 2000 RPM, maximum difference was at a lower frequency. It is believed that these variations in levels were due to vibrations induced in the duct walls. No specific cause could be determined since a consistent

in the case did not affect the soundness of the

[illegible]

relationship linking the frequency of maximum sound level variation to the duct dimensions could not be found. It was therefore decided to make all frequency spectrum readings at the duct center.

Overall sound-pressure levels were taken at the duct center and at three radial positions off the center. An average overall sound-pressure level was then obtained from the average of the four measured sound pressures.

The final preliminary check was a determination of the contribution of wind noise to the SPL throughout the frequency spectrum. The test was made for the  $A\frac{1}{2}$  fan at its rated speed. SPL's were measured with and without the microphone windscreen. The levels obtained with the screen were consistently below those measured without the screen, the larger differences occurring at high frequencies. (Fig. 9 - page A-10) This effect was expected, and it was decided to use the microphone windscreen for all further experimentation.

After these preliminary tests of the exponential horn, the effect of microphone radial and axial positions, and the effect of the windscreen, tests were commenced

rejection of the hypothesis of a simple sound level. It was therefore decided to make all frequency spectrum readings at the same level.

Typical sound-pressure levels were taken at the four points and at three radial positions off the center. An average overall sound-pressure level was then obtained from the average of the four readings.

The final preliminary work was a determination of the sensitivity of the noise to the air flow. The frequency spectrum, the flow rate and the air flow rate were measured with and without the microphone. The results obtained with the microphone were compared with those obtained without the microphone. The larger differences occurred at high frequencies. The flow rate was 1-10 l/min. The effect was significant, and it was decided to use the microphone throughout for all further experiments.

After these preliminary tests of the experimental setup, the effect of microphone radial and axial position, and the effect of the microphone level were examined.

to determine the sound-power output of the ventilating fan. SPL's were recorded for the  $A\frac{1}{2}$  fan at 14 speeds ranging from 800 to 3450 RPM. For the  $A1\frac{1}{2}$  fan, data were recorded at the same speeds as for the  $A\frac{1}{2}$ ; and, in addition, readings were made at 3800, 4200, and 4600 RPM. Levels were recorded with no back pressure; and the runs were repeated with the back pressure wind-screen in place at the horn mouth. SPL's were measured for both fans at each speed over a frequency range of 100 - 10,000 cps, using the one-third octave band analyzer for frequency selection. Overall levels were also recorded at each speed at four radial positions, and the average of these was taken as the overall SPL.

At the conclusion of these tests, the  $A\frac{1}{2}$  fan was operated in the reversed position. Using the octave-band analyzer, SPL'S were measured in the duct with the fan running at rated speed.

[illegible]

It was concluded that the  $\frac{1}{2}$  inch  
was required in the revised condition. Using the same  
data as before, the  $\frac{1}{2}$  inch was required in the same  
condition as before.

### III. POWER LEVEL

Power levels were used in the presentation of data obtained from these tests because in an acoustical analysis of ventilating duct systems, the basic quantity needed is acoustic power. Sound-pressure level in a duct, having no losses through its walls, decreases with increasing cross-sectional area; however, again neglecting losses, power level is independent of cross-sectional area.

Now consider a system in which wall losses are taken into account. If the sound power supplied to a duct system by a ventilating fan can be measured or computed, it is possible

- 1) To predict the sound-pressure levels in a room supplied by the ventilating system, if the duct wall losses and the propagation constants of the given system are known, and
- 2) To calculate the number of additional power absorption units in the duct system necessary to achieve sound-pressure levels below a specified value in the room.

# APPENDIX

Power levels were used in the determination of data obtained from these tests. It is assumed that the magnitude of potential back reaction, the back reaction needed to account for the back reaction, is small, being no larger than the back reaction with increasing power. However, again, neglected cases, power level is indicated at approximately equal.

The constant  $\alpha$  is given in which will be the same for all cases. It is the same power supplied to a given system as a function of the back reaction, it is possible.

- 1) To provide the same power level in a room supplied by the reacting system at the same level and the proportion of the given system is known, the
- 2) To calculate the number of additional power required when in the given system
- 3) To calculate the power level in the given system

Power level is defined by the following formula:-

$$PL = 10 \log_{10} \frac{P}{0.9 \times 10^{-13}}$$

P = Power in watts

The SPL in a duct neglecting transverse resonances is related to the power level by the following equation:-

$$SPL^* = PL - 10 \log_{10} A + 29.5 + \log_{10} \left( \frac{293}{T} \times \frac{P}{760} \right) \text{ db}$$

A = Duct cross-sectional area in  $\text{cm}^2$

T = Absolute temperature  $K^\circ$

P = Pressure, millimeters of mercury.

In this investigation pressure and temperature conditions were sufficiently close to standard to be able to neglect the last term in the relationship above.

Power level is defined by the following

formula:-

$$P_L = 10 \log_{10} \frac{P}{0.01 \times 10^{-12}}$$

where  $P$  = Power in watts

The SWR is a dual signalized frequency

response is related to the power level by the following

formula:-

$$SWR = 10 \log_{10} \frac{P}{0.01 \times 10^{-12}} + 10 \log_{10} \frac{1}{1 - \frac{1}{SWR^2}}$$

$A$  = Total cross-sectional

area in  $m^2$

$T$  = Absolute temperature  $^{\circ}K$

$S$  = Frequency, Hertz, of

radiation.

In this investigation between the temperature

variation and reflectivity does not appear to be a

direct relationship in the relationship space.

It is noted that the relationship between the

temperature and reflectivity is not a

direct relationship in the relationship space.

\* Appendix - Table 1-1

#### IV. RESULTS

##### Frequency Spectra

The investigation of noise spectra of the fans tested produced apparently good results. The previously used test procedure for Navy ventilating fans did not include a spectrum check, so there was no direct method available for checking the quality of the data. Since the noise producing mechanism of the axial-flow fan is similar to that of an airplane propeller, it was felt that the noise resulting from the two sources should have similar characteristics. Reliable data are available concerning the behavior of an aircraft propeller as a function of speed and shaft power<sup>2-3</sup>. The airplane propeller data agreed generally with the spectra obtained above 100 cps from the ventilating fans.

The detailed investigation of spectra obtained from fan A<sub>2</sub><sup>1</sup> at various speeds revealed distinct peaks at the fundamental and fourth harmonic of the blade frequency. (Fig. 2.) The vertical lines connect corresponding points on the spectrum curves and the harmonic curves. It can also be seen that the second harmonic had a negligible effect on the spectrum.

# IV. RESULTS

## Propagator Spectra

The investigation of noise spectra of the  
 time tested produced apparently good results. The pro-  
 cedure used test procedure for many existing tests  
 did not include a spectrum check, so there was no direct  
 means available for checking the quality of the data.  
 Since the noise produced mechanism of the test-flow fan  
 is similar to that of an electrical generator, it was felt  
 that the noise resulting from the two sources should have  
 similar characteristics. Results data are available  
 concerning the behavior of an electrical generator as a  
 function of speed and shaft power.<sup>2,3</sup> The electrical power  
 factor data varied generally with the speed obtained  
 above 100 rpm from the existing tests.

The detailed investigation of spectra obtained  
 from the  $\frac{1}{2}$  at various speeds revealed distinct peaks  
 at the fundamental and fourth harmonics of the blade  
 frequency. (Fig. 4.) The spectral lines correspond to  
 resonant points on the spectrum curve and the harmonic  
 curve. It can also be seen that the second harmonic had  
 a significant effect on the spectrum.

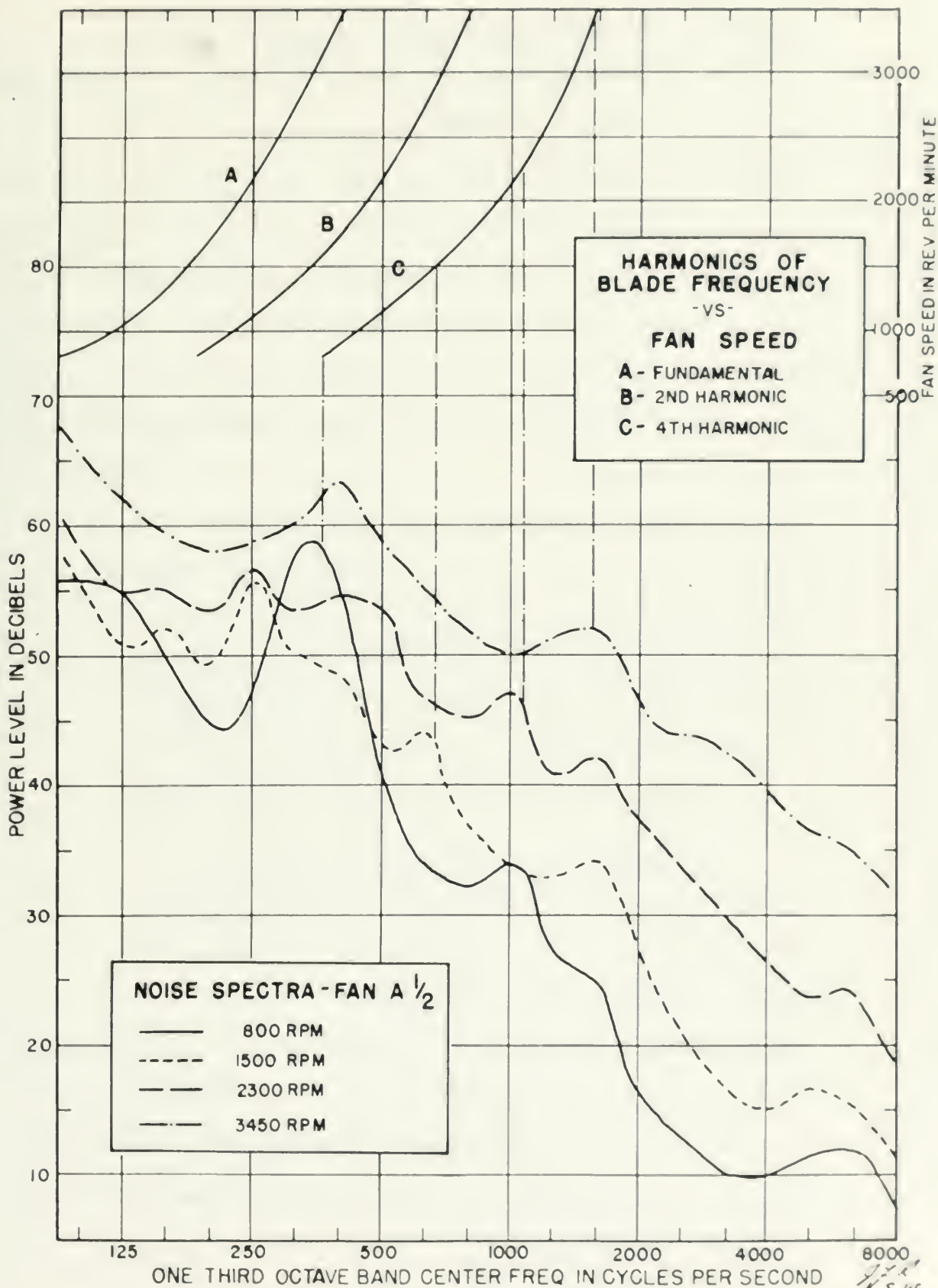


FIGURE 2

K.S.W.  
5/9/52



This is not in strict agreement with a theory developed by Professor O. K. Mawardi<sup>4</sup> which has been applied to axial-flow compressors for pressure variation near the blades. This theory, based on the assumption of incompressible flow, predicts a wave form at the blade tip containing large second and fourth harmonic components. No attempt will be made to explain the absence of the second harmonic, but the following deviations from the conditions upon which the theory is based should be noted:-

- a. Measurements were made relatively far from the blades.
- b. The blade section is not the standard Joukowsky air foil section used by Dr. Mawardi in his development of the theory for axial-flow compressors.
- c. The flow is probably not perfectly incompressible as assumed.

The latter deviation probably has little effect in the case of the  $A\frac{1}{2}$  fan, since a pressure check near the blades yielded a wave form which has predominant second and fourth harmonic components. On the other hand, compressibility and the high level of the turbulent noise are probably the reasons for the complete absence

This is not in strict agreement with a theory developed by Professor O. E. Schmidt<sup>1</sup> which has been applied to axial-flow compressors for pressure variation over the blades. This theory, based on the assumption of incompressible flow, predicts a wave form at the blade tip containing large second and fourth harmonic components. An attempt will be made to explain the absence of the second harmonic, but the following deviation from the conditions upon which the theory is based should be noted:-

- a. Measurements were made relatively far from the blades.
- b. The blade section is not the standard Joukowski air foil section used by Dr. Schmidt in his development of the theory for axial-flow compressors.
- c. The flow is probably not perfectly incompressible as assumed.

The latter deviation probably has little effect in the case of the  $\frac{1}{2}$  ton, since a pressure chord over the blades yielded a wave form which has pronounced second and fourth harmonic components. On the other hand, compressibility and the high level of the velocity make the possibility the reason for the complete absence

of identifiable harmonic peaks in the spectra of the  $A1\frac{1}{2}$  fan. (Fig. 3).

No analysis is known to the authors which applies to compressible flow around air foils. Therefore, the comparison with the propeller spectrum for agreement of trend is again used to estimate the quality of the test data. Although the octave spectrum of a propeller measured inside an airplane drops off much more rapidly than does that of a fan, as would be expected, the general trend is the same. This degree of agreement, coupled with the close agreement in trends for the two fans tested, indicates that the data presented probably give a true indication of the noise spectrum of the source.

Spectrum measurements were made for both fans with and without back pressure. The agreement in Fig. 4, indicated that the small increase in blade loading which resulted, produced an average reduction in spectrum level of about 2.5 db. It should be noted that the back pressures obtained were relatively small. For the  $A\frac{1}{2}$ , the maximum pressure obtained was 0.325 inches of water gauge, and for the  $A1\frac{1}{2}$  the maximum pressure was 0.70 inches of water gauge.

of identifiable harmonic lines in the spectra of the  $\frac{1}{2}$  ton. (Fig. 5).

As indicated in Figure 5, the spectrum which applies to compressible flow around air foils. There-fore, the comparison with the compressible spectrum for agreement of level is again used to estimate the quality of the test data. Although the degree of agreement of the spectra measured inside an airplane drops off much more rapidly than does that of a fan, as would be expected, the general trend is the same. This degree of agreement, coupled with the close agreement in trends for the two fans tested, indicates that the data presented probably give a true indication of the noise spectrum of the source.

Positive measurements were made for both fans with and without back pressure. The agreement in Fig. 4, indicated that the small increase in blade loading when needed, produced an average reduction in spectral level of about 2-3 db. It should be noted that the back pressure obtained were relatively small. For the  $\frac{1}{2}$  ton, the maximum pressure obtained was 0.005 inches of water gauge, and for the  $\frac{1}{4}$  ton maximum pressure was 0.02 inches of water gauge.

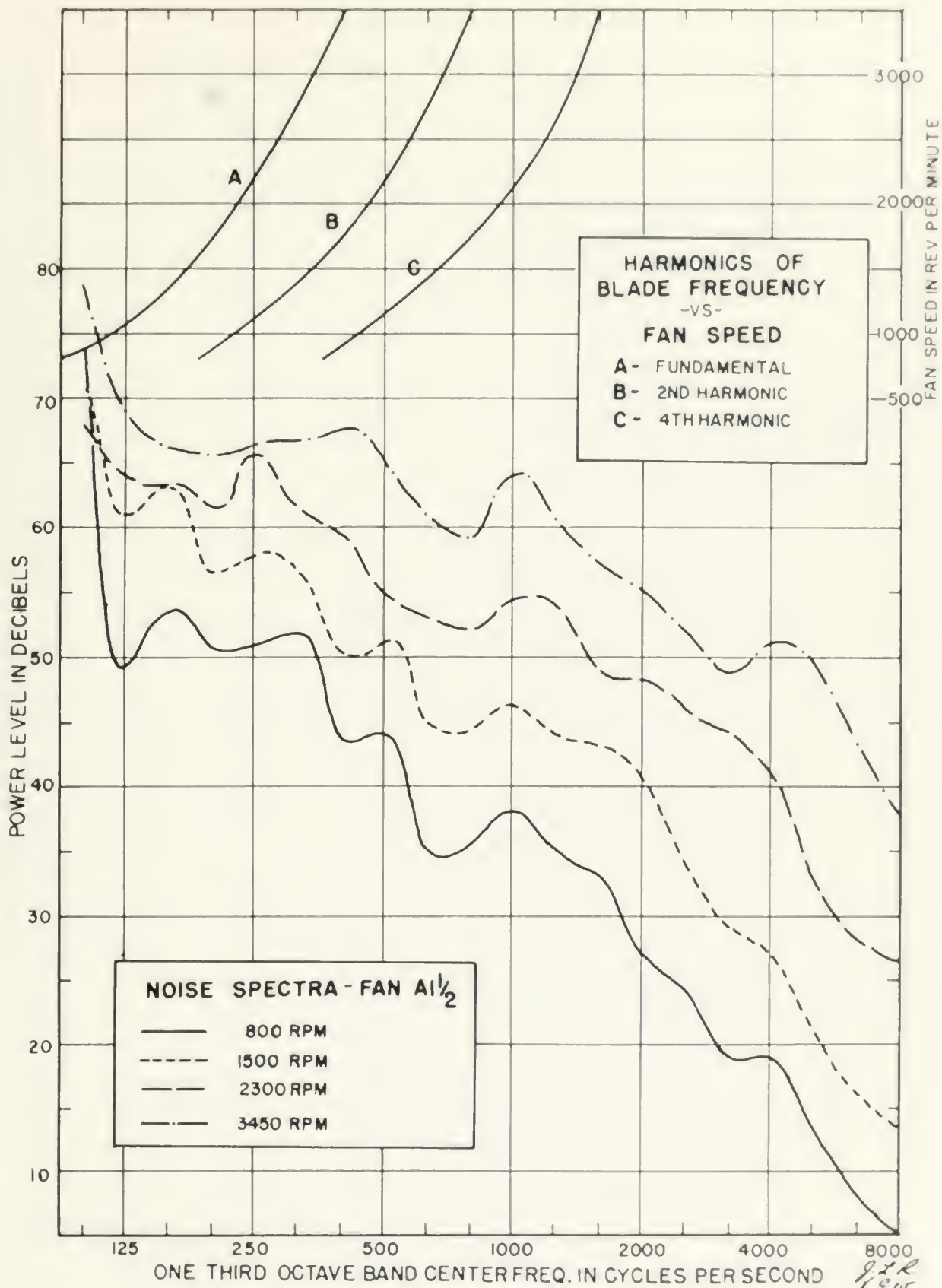


FIGURE 3

922  
125  
5/9/52



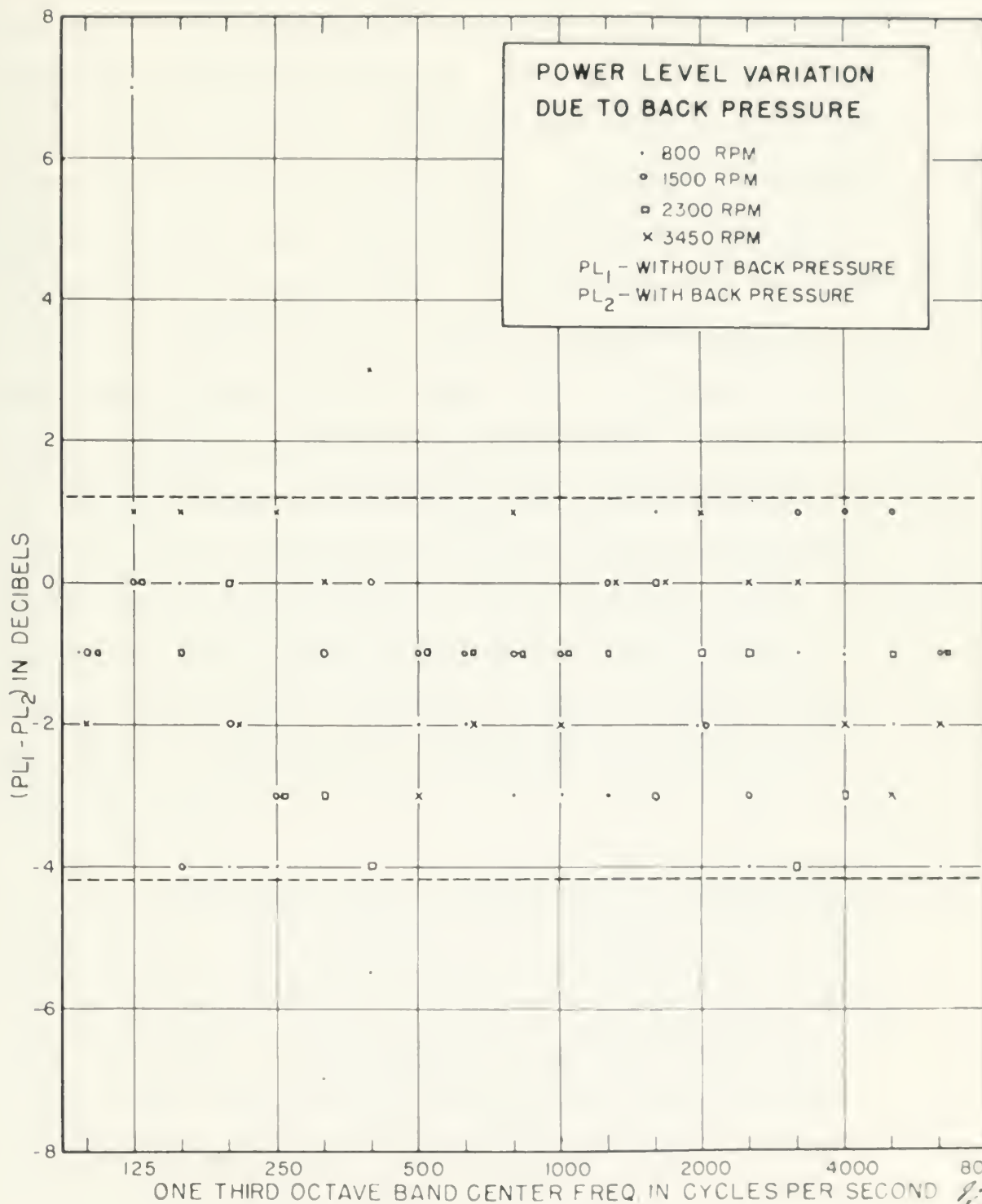


FIGURE 4

822  
 L.E.W.  
 5/1/51



### Overall Power Level

The average overall sound-power levels in decibels were calculated and plotted for the zero back pressure condition in Fig. 5. The small back pressures used caused very small reduction in overall power level from the zero back pressure case. At speeds above 2000 RPM, the plots give smooth curves of increasing power level with increasing speed. It is noted that the power level at 3200 RPM for the  $A_{1\frac{1}{2}}$  fan is 6.5 db higher than the smoothed curve. This value was caused primarily by an unusually high sound-pressure level in the 80 to 125-cps region. It is felt that this high level was a result of duct and associated system vibrations rather than the fan output. Large floor and duct vibrations were noted at this speed. Since overall power levels at all other speeds form a smooth curve, the value at 3200 RPM was neglected in drawing the smoothed curve.

The major cause of noise in the ventilating fans is the beating of the air by the fan blades and the disturbing influence of the fan straightening vanes and fan casing. In the  $A_{2\frac{1}{2}}$  fan, high sound-pressure levels were noted at high frequencies after the fan had been operating for some length of time. It is

Overall Power Level

The average overall sound-power levels in decibels were calculated and plotted for the two peak pressure conditions in Fig. 5. The small peak pressure used caused very small reduction in overall power level from the same peak pressure case. At speeds above 2000 RPM, the plots give smooth curves of increasing power level with increasing speed. It is noted that the power level at 3200 RPM for the  $\frac{1}{2}$  inch is 2.9 dB higher than the smoothed curve. This value was caused relatively by an unusually high sound-pressure level in the 50 to 100-cps region. It is felt that this high level was a result of flow and associated system vibrations rather than the fan output. Large flow and dust vibrations were noted at this speed. Since overall power levels at all other speeds form a smooth curve, the value at 3200 RPM was neglected in drawing the smoothed curve.

The major cause of noise in the ventilating fans is the beating of the air by the fan blades and the disturbing influence of the fan revolving vanes and fan casing. In the  $\frac{1}{2}$  inch high sound-pressure levels were noted at high frequencies when the fan had been operating for some length of time. It is

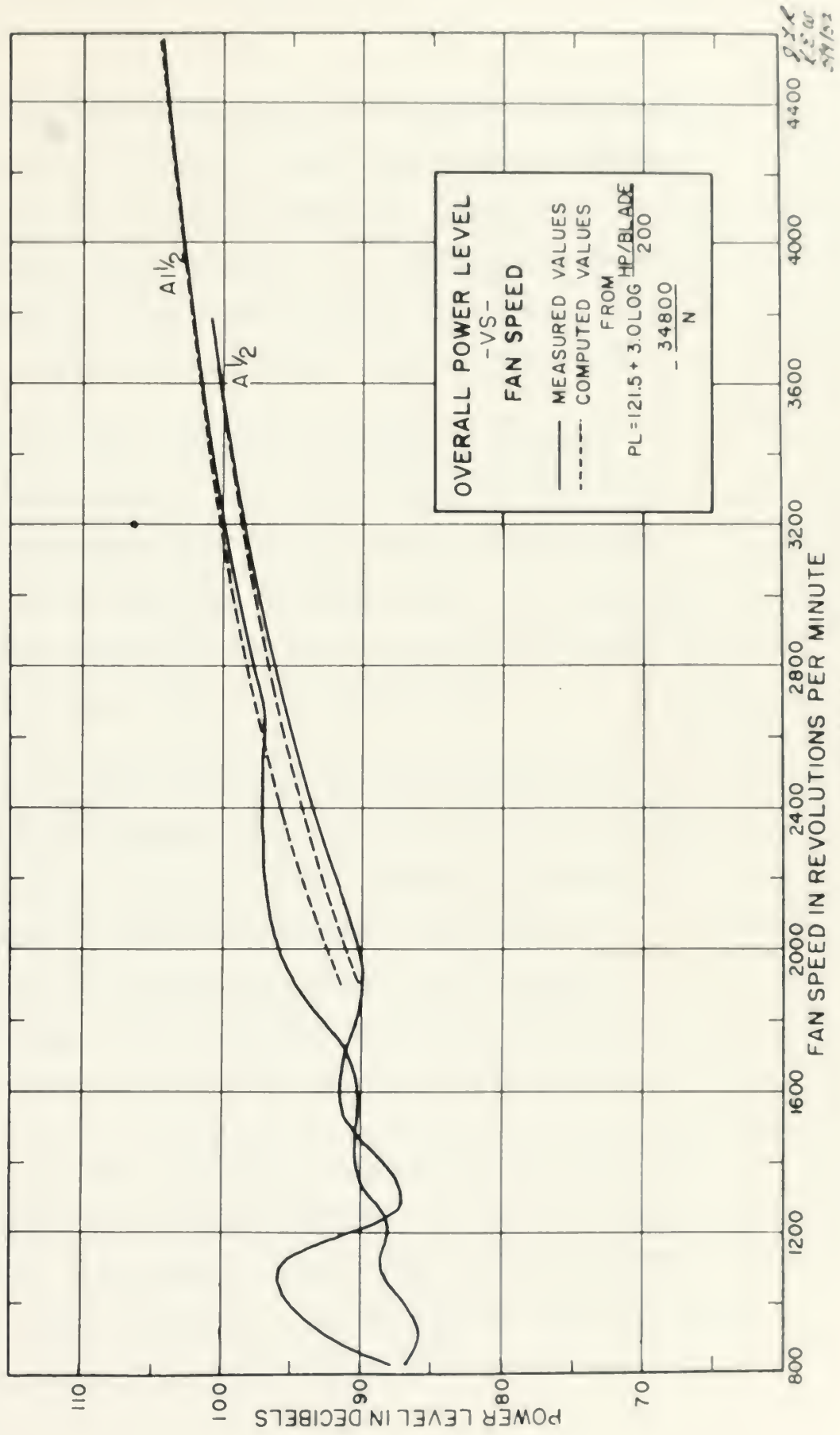


FIGURE 5



believed that these high levels were caused by fan motor noise. This high frequency noise was clearly audible without earphones, and with earphones could be heard in frequency bands above 5000 cps. In testing the  $A\frac{1}{2}$  fan, large differences were noted between the overall level at the duct center and the level near the duct wall.

It is believed that vibrations, caused by improper fan motor construction, were transmitted through the duct walls causing higher sound-pressure levels near the wall. In the  $Al\frac{1}{2}$  fan, no motor noise was observed; and a maximum difference of 3 db was observed between levels at the duct center and near the wall.

An empirical formula has been derived for sound levels of airplane propeller noise.<sup>2-3</sup> This formula is based on data measured in the aircraft cabin and is a function of engine horsepower, propeller tip velocity, and the minimum propeller tip clearance. The sound-power levels computed by this formula correspond to that measured in the 75 - 150-cps octave.

A similar empirical formula has been derived by the authors for ventilating fans. In the aircraft measurements, the highest sound level was consistently in the 75 - 150-cps octave. In the  $A\frac{1}{2}$  and  $Al\frac{1}{2}$  ventilating fans, high levels were measured in this region; but at

believed that these high levels were caused by fan motor noise. This high frequency noise was clearly audible without response, and with earphones could be heard in frequency bands above 5000 cps. In testing the  $\frac{1}{2}$  fan, large differences were noted between the overall level at the duct center and the level near the duct wall.

It is believed that attenuation, caused by impedance fan motor construction, were transmitted through the duct walls causing higher sound-pressure levels near the wall. In the  $\frac{1}{2}$  fan, no motor noise was observed and a maximum difference of 3 db was observed between levels at the duct center and near the wall.

An empirical formula has been derived for sound levels of airplane propeller noise. This formula is based on data measured in the aircraft cabin and in a location of engine development, propeller tip velocity, and the minimum propeller tip clearance. The sound-power levels computed by this formula correspond to that measured in the 75 - 150-cps octave.

A similar empirical formula has been derived by the authors for ventilating fans. In the aircraft measurements, the highest sound level was consistently in the 75 - 150-cps octave. In the  $\frac{1}{2}$  and  $\frac{1}{4}$  ventilating fans, high levels were measured in this region, but at

some speeds, higher sound levels were observed at higher frequencies. Thus, it seemed more plausible to base the derived formula for ventilating fans on overall power level rather than the level of any particular octave. The formula below was derived to give sound-power levels in good agreement with the measured values. It was noted from the experimental data that the PL curves for the two fans were parallel above 2600 RPM. A tip speed term, as in the aircraft formula, would give different slopes for fans of different diameters. The desired result was attained by replacing the tip speed term with a function of rotational speed.

$$PL = 121.5 + 3.0 \log_{10} \frac{HP/Blade}{200} - \frac{34800}{n} + 10 \log_{10} \frac{N}{7}$$

Equation 1

PL = Power Level in Decibels

HP = Total Fan Horsepower

n = Fan Speed, RPM

N = Number of Blades

The total horsepower delivered to the  $Al\frac{1}{2}$  fan by its series wound motor was computed at each speed by measuring the fan motor terminal voltage and the armature current. The armature resistance was determined by test to be 1.75 ohms. The horsepower, calculated from these measurements,\* varied closely as the

---

\* Appendix - Page A-34

from which, slight wave levels were observed at  
 higher frequencies. Thus, it seemed more probable  
 to have the surface formula for localized wave as  
 overall wave level rather than the level of any single  
 surface. The formula was then derived to give  
 overall level in good agreement with the measured  
 values. It was noted from the experimental wave data  
 that it seemed for the low wave parallel wave

also that a tip wave level as in the surface formula  
 would give different slopes for two of different dis-  
 tances. The highest would be obtained by assuming  
 the tip speed was a function of potential energy.

$$V = 100 \times 0.5 \times 10^{-10} \times \frac{0.0001}{0.0001} = 10 \times 10^{-10}$$

Question 1  
 It is known that in practice  
 the total wave level is measured  
 by the total wave level  
 as the level, the  
 the level of the wave is the level of the wave

The total wave level is the level of the wave  
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square of the fan speed over the speed range tested. (Fig. 11, page A-35) Motor rotational losses were neglected in computing the horsepower developed at each speed. In the  $A\frac{1}{2}$  unit, the horsepower delivered by the compound wound motor to its fan was not measured. The measured horsepower for the  $Al\frac{1}{2}$  fan at rated speed (3450 RPM) was 0.382 HP with no back pressure applied. The motor name plate for the  $Al\frac{1}{2}$  fan indicated a rating of 1.1 HP at rated speed. For the  $A\frac{1}{2}$  fan, the rated horsepower at 3450 RPM was 0.4 HP. It was assumed that the measured horsepower for the  $A\frac{1}{2}$  fan at 3450 RPM with zero back pressure was

$$\frac{0.4}{1.1} \times 0.382 = 0.140 \text{ HP}$$

The horsepower at the other speeds were then calculated by assuming that in the  $A\frac{1}{2}$ , as in the  $Al\frac{1}{2}$ , total fan horsepower varied as the square of the speed. These horsepower were then used in Equation 1 to obtain computed sound-power levels.

Equation 1 is plotted for both fans in Fig. 5. The derived sound power formula gives agreement to within 1 db of the measured values in the speed range above 2600 RPM for both fans.

The variation in octave-band spectrum caused by reversing the fan position, making the measuring duct end the intake end, is shown in the frequency spectrum plot of Fig. 6.

known of the fan speed with the speed range tested.  
 (Fig. 11, page A-33) (Other relations) known were  
 neglected in computing the horsepower developed at  
 each speed. In the  $\frac{1}{2}$  mile, the horsepower delivered  
 by the compound wound motor to the fan was not measured.  
 The measured horsepower for the  $\frac{1}{2}$  fan at rated speed  
 (1450 rpm) was 0.305 HP with no back pressure applied.  
 The motor name plate for the  $\frac{1}{2}$  fan indicated a rating  
 of 1.1 HP at rated speed. For the  $\frac{1}{2}$  fan, the rated  
 horsepower is 3450 RPM was 0.4 HP. It was assumed that  
 the measured horsepower for the  $\frac{1}{2}$  fan at 3450 RPM  
 with zero back pressure was

$$\frac{0.4}{1.1} \times 0.305 = 0.110 \text{ HP}$$

The horsepower at the other speeds were then calculated  
 by assuming that in the  $\frac{1}{2}$ , as in the  $\frac{1}{2}$ , total fan  
 horsepower varied as the square of the speed. These  
 horsepower were then used in Equation 1 to obtain  
 computed sound-power levels.

Equation 1 is plotted for zero loss in Fig. 2.  
 The derived sound-power levels give agreement to within  
 1 db of the measured values in the speed range shown  
 from the fan test.

The variation in average sound-power level  
 as measured by the fan (indicated) using the average  
 loss and the losses are shown in the frequency  
 spectrum plot of Fig. 3.

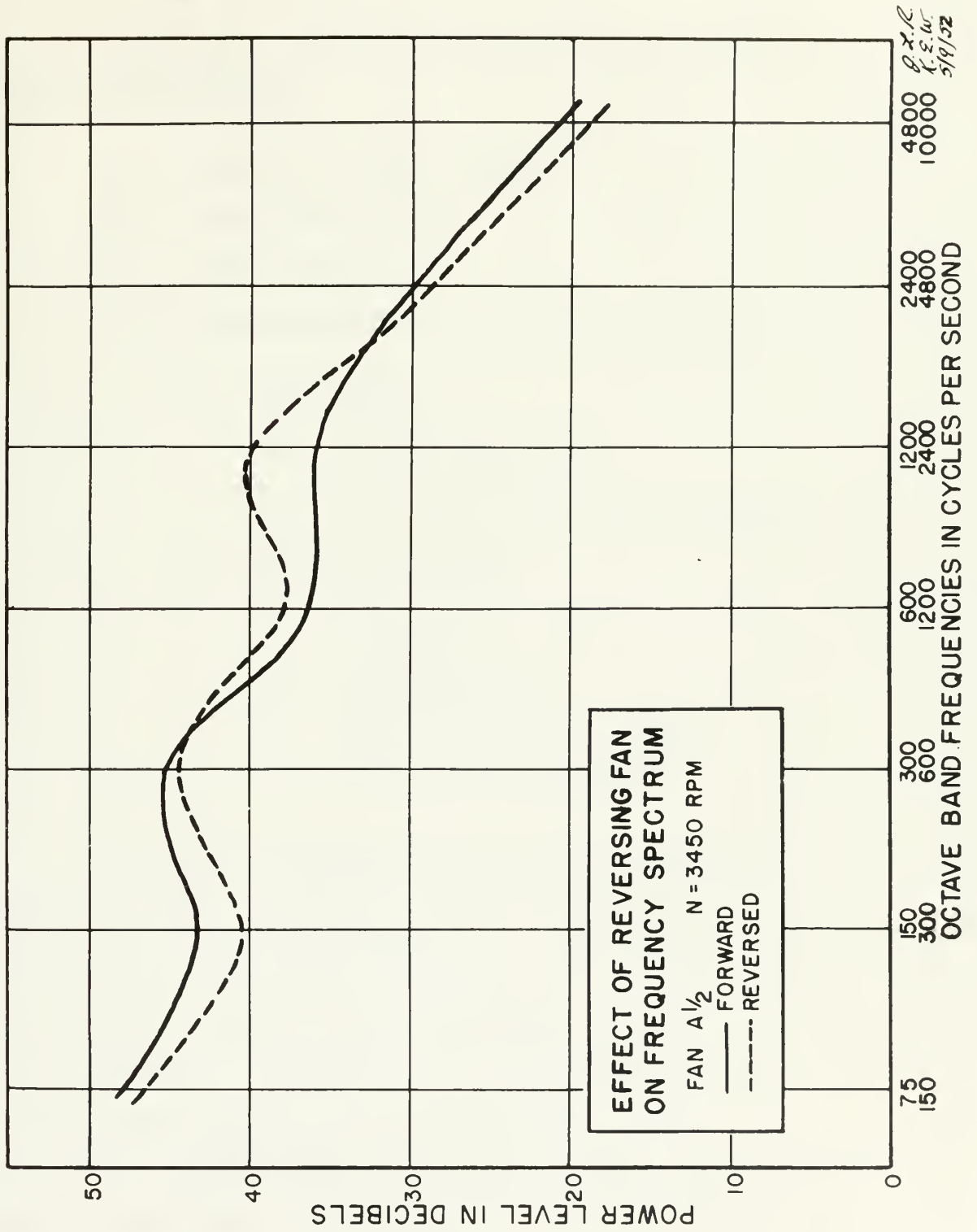


FIGURE 6

P. S. R.  
K. S. W.  
5/9/52



## V. CONCLUSIONS

The points on which a proposed test method should be judged are:-

- A. Quality of data obtained
- B. Usability of data
- C. Repeatability
- D. Characteristics of the test equipment
  - 1. Test Setup
    - a. Reproduceability
    - b. Cost and ease of manufacture
  - 2. Measuring System
    - a. Accuracy
    - b. Availability
    - c. Time required to obtain accurate measurements

In the development of a new test procedure, probably the most difficult point to judge accurately is the quality of the data obtained. On the basis of the consistent trends in spectrum measurements and smooth variations in overall PL as a function of fan speed, the data appear to be satisfactory. This appearance is further reinforced by the good repeatability of datum points which was observed. Variations from one

# 7. CONCLUSIONS

The points on which a proposed test method

should be judged are:-

- A. Quality of data obtained
- B. Quantity of data
- C. Reproducibility
- D. Characteristics of the test equipment

## 1. Test Method

- a. Reproducibility
- b. Cost and ease of maintenance

## 2. Measuring System

- a. Accuracy
- b. Availability
- c. Time required to obtain accurate measurements

In the development of a new test procedure, probably the most difficult point to judge accurately is the quality of the data obtained. On the basis of the comments made in previous paragraphs and much variation in overall  $\bar{R}$  as a function of the speed, the data appear to be satisfactory. This equipment is further evidenced by the good reproducibility of data points which was observed. Variations from one

time of measurement to another seldom exceeded 1 db. A further indication that the data obtained are good is the partial agreement of the spectra of the  $A\frac{1}{2}$  fan with theory applied to axial-flow compressors.

Usability of the data is another point which is difficult to determine when the type data obtained has not been available before.

It is known that this type of data will permit accurate calculations of sound-pressure levels in rooms supplied by a ventilation system if, in addition, the power losses in the duct are known and if available propagation constants in duct liners are used. In other words, only if power levels are known can predictions of levels in rooms be attempted. In addition, this type of measurement permits intercomparison of fans on a logical basis. Also, the spectra obtained could possibly be employed by design engineers to determine the exact origin of the fan noise and thereby assist in redesign to reduce the sound output of axial-flow fans. Through empirical formulas, such as the one presented here, more exacting acceptance standards might be set down. Consideration of only these possibilities leads to the conclusion that this test method yields usable data.

time of measurement is another value measured  $\pm 40$ .  
 A further remark is that the data obtained are good  
 is the partial agreement of the order of the  $\frac{1}{2}$  law  
 with theory applied to catalytic phenomena.

Recovery of the data is another point which  
 is difficult to determine when the type data obtained  
 are not given in advance.

It is known that this type of data will permit  
 accurate calculation of point-pressure levels in some  
 examples as a verification system it, in addition, the  
 point losses in the case are known and it is possible to  
 obtain a comparison in that theory are used. In other  
 words, only if point losses are given can predictions of  
 levels in some be compared. In addition, this type  
 of measurement permits investigation of loss on a local  
 basis. Also, the spectra obtained would possibly be  
 employed by design engineers to determine the exact nature  
 of the loss noise and thereby assist in reducing the  
 losses the system subject of axial-flow fans. Through  
 analytical formulas, such as the one presented here, some  
 existing equipment standards might be set back. The  
 inclusion of only these possibilities leads to the  
 conclusion that this type of data is valuable.

It the test method qualifies on points A, B, and C, (p. 29 ) it is then worthwhile to examine the test setup. In the arrangement used for these tests, it can be seen that the duct and exponential horn, built of standard size materials from simple plans lend themselves to exact reproduction. This fact is important in standardizing an acceptance test procedure. Another point in favor of the system is that it is inexpensive and easy to manufacture.

The final component to be considered in a test method is the measuring system. Again, the results of an examination are favorable for the system employed. Each component is of good accuracy when properly calibrated. None are dependent upon battery power and are therefore quite stable. Furthermore, the necessary calibration is quite simple and requires little time. Finally, the time required to obtain good data is short due to the relatively small swing in the readings afforded by the use of the one-third octave filters as opposed to a sound analyzer. Because one-third octave band filters are not readily available in the United States, full octave-band filters should probably be specified for use in government test facilities.

It has been said that the only way to solve the problem of the future is to solve the problem of the present. This is a very important point in that it is the only way to solve the problem of the future. This is a very important point in that it is the only way to solve the problem of the future.

The final component to be considered is a best method in the measuring system. Again, the results of an examination are favorable for the system employed. Each component is of good accuracy when properly calibrated. None are dependent upon battery power and are therefore quite simple. Furthermore, the necessary calibration is quite simple and requires little time. Finally, the time required to obtain good data is short even for the relatively small water in the channels. It is the use of the one-third octave filter as opposed to a sound analyzer. Because one-third octave band filters are not readily available in the United States, full octave band filters should generally be specified for use in government test facilities.

The indications are that on all points considered, the proposed method fulfills the requirements. Although the evidence is not conclusive concerning the quality of the data, it is felt that further exploitation of this procedure is warranted because of the simplicity of the setup and the varied types of data obtainable.

The indications are that on all points considered, the proposed method satisfies the requirements. Although the evidence is not conclusive concerning the quality of the data, it is felt that further application of this procedure is warranted because of the simplicity of the setup and the varied types of data available.

## VI. RECOMMENDATIONS

In the light of the results obtained and the conclusions reached, the following recommendations are suggested relative to further study of the ventilating fan test proposed herein:-

1. The duct system and measuring equipment used in this test, or a similar test setup, should be employed for future investigation.

2. Several other fans should be tested to confirm the accuracy of the overall sound-power formula and to compare the frequency spectrum with those obtained for the  $A\frac{1}{2}$  and the  $Al\frac{1}{2}$  fans. The overall sound-power level formula, as stated in the report (or one derived to give good agreement with measured data for these and other fans), could be used as a design criterion or as an acceptance specification for standard Navy and for commercial ventilating fans.

3. Test  $A\frac{1}{2}$  and  $Al\frac{1}{2}$  fans with a-c drive motors to investigate the effect of motor noise.

4. Higher back pressures in the duct should be arranged for without disturbing the sound field. Investigation of power levels at these increased fan loadings should be made.

# RECOMMENDATIONS

In the light of the results obtained and the conclusions reached, the following recommendations are suggested relative to further study of the vibrating fan test project herein:-

1. The test system and measuring equipment used in this test, or a similar test setup, should be employed for future investigation.

2. Several other fans should be tested to confirm the accuracy of the overall sound-power levels and to compare the frequency spectrum with those obtained for the  $\frac{1}{2}$  and  $1\frac{1}{2}$  fans. The overall sound-power level results, as stated in the report (or one derived to give good agreement with measured data for these and other fans), could be used as a design criterion for an appropriate specification for standard fans and for commercial vibrating fans.

3. Test  $\frac{1}{2}$  and  $1\frac{1}{2}$  fans with a-v drive motors to investigate the effect of motor noise.

4. Higher sound resistance in the duct should be investigated without disturbing the sound field. Investigation of power levels at other distances from the fan should be made.

5. Investigate more fully the effect on sound-pressure level of varying the radial position of the microphone. Check this effect at various speeds and frequencies in order to obtain a relation between radial sound-pressure level variation and fan speed, frequency, and duct dimensions. (The radial change in levels for the  $A\frac{1}{2}$  fan may have been caused by poor motor construction.) Further damping of the duct, using sand, may decrease this effect.

6. Increase measuring duct length and increase the number of duct straightening vanes to reduce possible turbulent effects at the measuring section.

7. Make sound-pressure level measurements at the intake end of the fans and obtain complete directivity data for this end of the fans.

8. In order to obtain frequency data quickly with an adequate degree of frequency selection, at least a one-third octave filter should be used. For a more accurate investigation of the appearance of the fundamental blade frequency and its harmonics in the fan sound output, a frequency analyzer or wave analyzer with a very narrow band should be used.



9. The test set-up should be mounted on a rigid foundation (cement floor) to aid in minimizing system vibrations.

10. To eliminate motor noises being transmitted through the duct walls to the measuring section, insert a short (about 2") canvas sleeve between the expansion section and the measuring duct.

11. Test this and other kinds of microphone windscreens to determine more precisely their effect on the frequency spectra and overall power levels.

The windscreen used in this series of tests is shown in PLATE V.

9. The lead was-up should be mounted on a right foundation (about 15cm) to aid in minimizing expansion effects.

10. In situations where lead is being used, it should be placed through the lead walls to the remaining section. There is about (about 2") space between the expansion section and the remaining lead.

11. Lead will not alter state of equilibrium. It is necessary to determine more precisely how it affects the frequency spectrum and overall power levels. The windscreen used in this series of tests is shown

in PLATE V.

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A. APPARATUS

1. Octave-Band Analyzer, General Radio Company  
Type 1550-A, No. 101.
2. Slide-wire Rheostate (3)  
(1) 107 Ohm, 3.3 Amps. No. 96737  
(2) 120 Ohm, 2.5 Amps, No. 3383X, 1748X
3. MIT Acoustics Laboratory Condenser Microphone  
Amplifier AL-167
4. Ballantine Laboratories Voltmeter  
Model 643, No. 196266.
5. One-Third Octave Band Analyzer, Telefon Fabrik  
Automatic A/S and Kobenhaven Filter 11203-4.
6. Strobotac, Type No. 631-B, No. 11071, General  
Radio Company.
7. Motor Control Starting Box, Cutler-Hammer Company.
8. Microphone, Condenser, Type 21-B, Altec-Lansing  
Corporation
9. Simpson Voltmeters (2) Simpson Electric Company  
Chicago, Model 260, Nos. 837130, 837131.
10. Elison Inclined Draft Gage, Elison Company  
Chicago.
11. U. S. Navy Axial-Flow Fan,  $A\frac{1}{2}$  DIW5, Mfr. Ser. No.  
A-8704. Buffalo Forge Company, Buffalo.
12. U. S. Navy Axial-Flow Fan,  $A\frac{1}{2}$  DIW5, Mfr. Ser. No.  
A-22201. Buffalo Forge Company, Buffalo.

## APPENDIX

1. Gossage-Bell Instrument, Gossage-Bell Company  
Type 1220-A, No. 100.
2. Eichenlaub Instrument (3)  
(1) 100 Ohm, 2.5 Amps, No. 100737  
(2) 100 Ohm, 2.5 Amps, No. 100737, 1962
3. MIT Electronics Laboratory, Massachusetts Institute of Technology  
Model 100-A, No. 100737
4. Bell Telephone Laboratories, New Jersey  
Model 100-A, No. 100737
5. Gossage-Bell Instrument, Gossage-Bell Company  
Type 1220-A, No. 100737
6. Gossage-Bell Instrument, Gossage-Bell Company  
Type 1220-A, No. 100737
7. Gossage-Bell Instrument, Gossage-Bell Company  
Type 1220-A, No. 100737
8. Gossage-Bell Instrument, Gossage-Bell Company  
Type 1220-A, No. 100737
9. Gossage-Bell Instrument, Gossage-Bell Company  
Type 1220-A, No. 100737
10. Gossage-Bell Instrument, Gossage-Bell Company  
Type 1220-A, No. 100737
11. U. S. Navy Radio Laboratory, 1000 15th St., N.W., Wash., D.C.  
Type 1220-A, No. 100737
12. U. S. Navy Radio Laboratory, 1000 15th St., N.W., Wash., D.C.  
Type 1220-A, No. 100737

B. DATA1. Calibration Data

## a. System

$$1 \text{ volt} = 1 \text{ dyne/cm}^2$$

 $V_{\text{out}}$  = Amplifier Output Voltage

 $V_{\text{mic}}$  = Microphone Output Voltage

Response of 21-B microphone to -48.6 db is about -45.5 db

$$20 \log_{10} \frac{V_{\text{mic}}}{1} = -45.5 \text{ db for } 74 \text{ db}$$

$$\log_{10} V_{\text{mic}} = 2.275$$

$$V_{\text{mic}} = \frac{1}{188} = 0.0053 \text{ v for } 74 \text{ db}$$

Line Amplifier Gain = 40 db

$$20 \log_{10} \frac{V_{\text{out}}}{V_{\text{mic}}} = 40 \text{ db}, \quad \frac{V_{\text{out}}}{V_{\text{mic}}} = 100$$

$$V_{\text{out}} (74 \text{ db}) = 0.53 \text{ v}$$

$$V_{\text{out}} (80 \text{ db}) = 1.06 \text{ v}$$

$$\approx 1.0 \text{ v}$$

This gives scale factor for Ballantine Voltmeter

b. Microphone Calibration (See Fig. 7 for frequency calibration of microphone.)

Calculation Data

- a.  $V_{out} = 1 \text{ cycle/sec}$
- $V_{out} = \text{Amplifier Output Voltage}$
- $V_{in} = \text{Microphone Output Voltage}$

Frequency of 20 Hz is chosen for -40 dB is about -45 dB

$$20 \log_{10} \frac{V_{out}}{V_{in}} = -40 \text{ dB for } 20 \text{ Hz}$$

$$\log_{10} \frac{V_{out}}{V_{in}} = -2$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{100} = 0.01 \text{ for } 20 \text{ Hz}$$

Line amplifier gain = 40 dB

$$20 \log_{10} \frac{V_{out}}{V_{in}} = 40 \text{ dB}$$

$$\log_{10} \frac{V_{out}}{V_{in}} = 2$$

$$\frac{V_{out}}{V_{in}} = 100$$

$$V_{out} (75 \text{ Hz}) = 0.5 \text{ V}$$

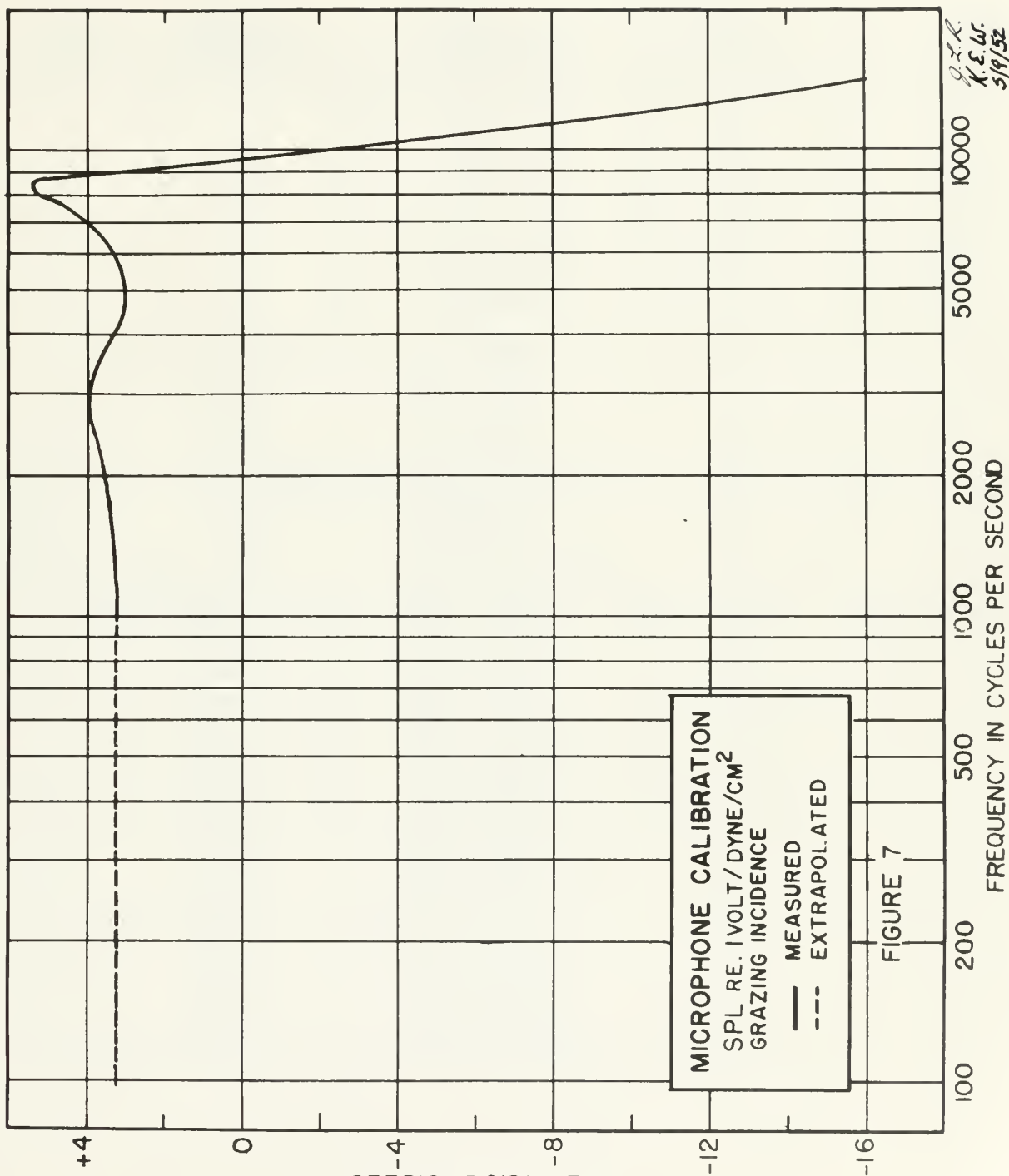
$$V_{out} (50 \text{ Hz}) = 1.0 \text{ V}$$

$$\approx 1.0 \text{ V}$$

These data are used for microphone calibration

- b. Microphone calibration (see fig. 7 for frequency calibration of microphone.)

RE -48.6 DECIBELS





## c. One-Third Octave Filter Calibration

Band Number	Band Center Frequency	Band Bounding Frequencies	Band Level Correction
1	50	45-57	-4
2	63	57-71	-3
3	80	71-90	-2
4	100	90-114	-2
5	125	114-142	-1
6	160	142-180	-1
7	200	180-228	-1
8	250	228-284	-1
9	320	284-360	-1
10	400	360-456	0
11	500	456-568	0
12	630	568-720	0
13	800	720-912	0
14	1000	912-1136	0
15	1250	1136-1440	0
16	1600	1440-1824	0
17	2000	1824-2272	0
18	2500	2272-2880	0
19	3200	2880-3648	0
20	4000	3648-4544	0
21	5000	4544-5760	-1
22	6300	5760-7296	-1
23	8000	7296-9088	-2
24	10000	9088-11520	-2

## c. One-Third Native Wildflower Collection

Band Number	Band Center Frequency	Band Bandwidth Frequency	Band Level Correction
1	50	45-55	-4
2	63	57-71	-3
3	80	71-90	-3
4	100	90-114	-2
5	125	114-145	-1
6	160	145-180	-1
7	200	180-225	-1
8	250	225-264	-1
9	320	264-300	-1
10	400	300-400	0
11	500	400-500	0
12	630	500-750	0
13	800	750-912	0
14	1000	912-1130	0
15	1250	1130-1440	0
16	1600	1440-1800	0
17	2000	1800-2250	0
18	2500	2250-2680	0
19	3200	2680-3040	0
20	4000	3040-3640	0
21	5000	3640-5000	-1
22	6300	5000-7500	-1
23	8000	7500-9000	-2
24	10000	9000-11500	-2

2. Horn Check

Readings of SPL\* at axial positions along horn length, using fan  $A\frac{1}{2}$ .

Axial Horn Position	Speed						
	Ambient	1000	1500	2000	2500	3000	3450
1	48	65	60	62	64	68	69
2	48	65	59	60	64	67	69
3	48	63	57	59	63	66	67.5
4	48	61	57	57	63	62.5	66
5	48	60	57	56.5	61	62	66
6	48	58	57	56	60	60.5	63

\* All readings  $\pm 1.5$  db

$\Delta IL = \Delta SPL$  (Reference Sound-Pressure Level at Horn Throat, Position 2)

$\Delta SPL$ Position	Speed					
	1000	1500	2000	2500	3000	3450
3	-2	-2	-1	-1	-1	-1.5
4	-4	-2	-3	-1	-4.5	-3
5	-5	-2	-3.5	-3	-5	-3
6	-7	-2	-4	-4	-6.5	-6

See Fig. 10, p. A-32

Location of 24" at axis position along base  
length, using 100'.

Speed	Location					
	1000	1500	2000	2500	3000	3500
1	48	60	68	74	82	88
2	48	60	68	74	82	88
3	48	60	68	74	82	88
4	48	60	68	74	82	88
5	48	60	68	74	82	88
6	48	60	68	74	82	88

All readings 2.5 to 3.0

ALL = 24" (Reference Point-Reference Level at 100')  
(Thrust, Position 2)

Speed	Location					
	1000	1500	2000	2500	3000	3500
1	-2	-2	-1	-1	-1	-1.5
2	-4	-2	-2	-1	-1.5	-2
3	-2	-2	-2.5	-3	-3	-3
4	-7	-2	-4	-4	-3.5	-5

See Fig. 10, p. 4-32

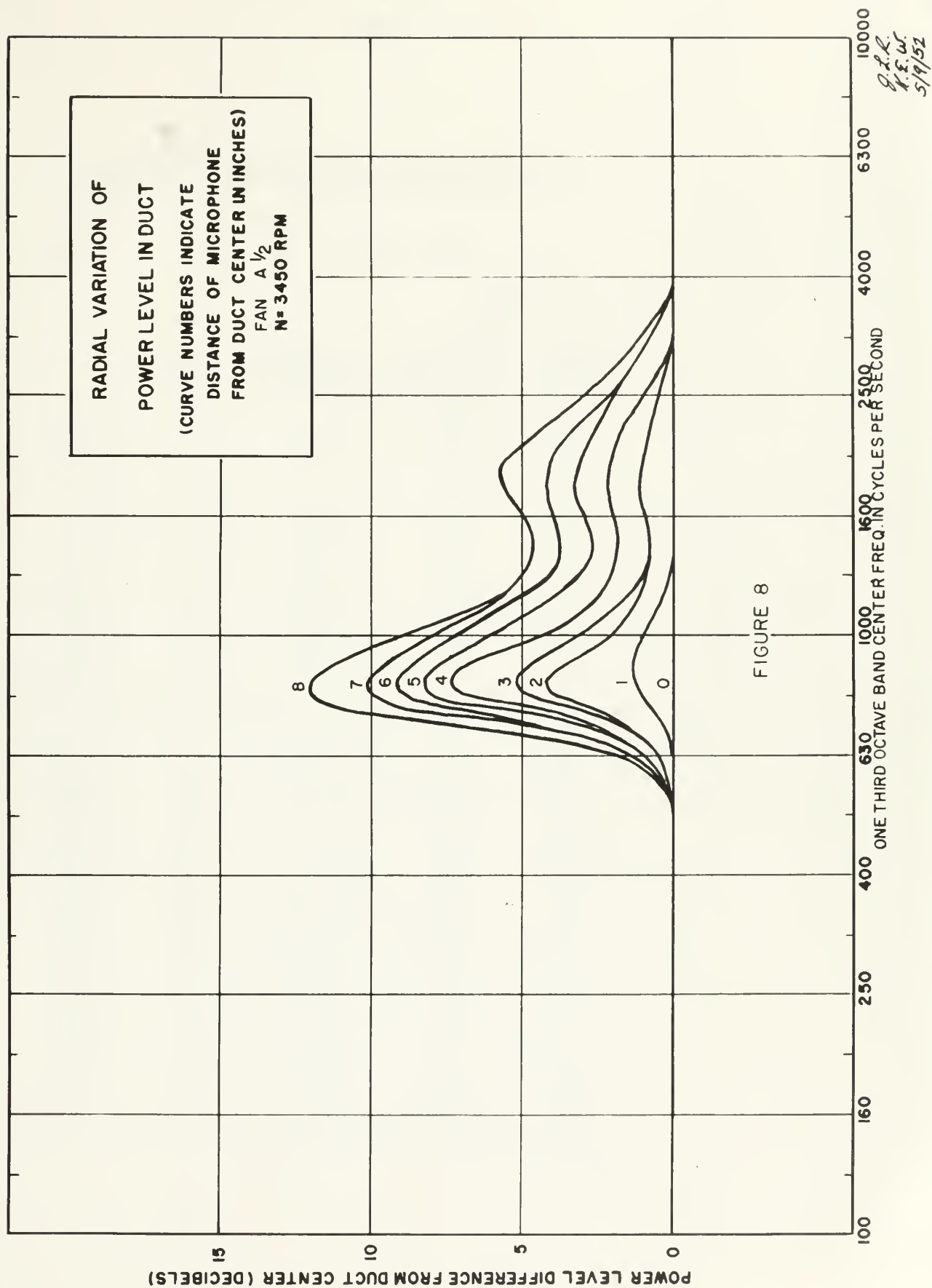
### 3. Radial Check ( $A_2^2$ )

SPL

f	Band	n - 1000				n = 2000				n = 3450								
		0"	3"	6"	8"	0"	3"	6"	8"	0"	1"	2"	3"	4"	5"	6"	7"	8"
100	4	66	66	65	65	75	73	72	72	78	77	78	78	78	78	78	78	78
125	5	63	63	63	63	71	69	68	69	77	76	77	76	77	77	76	76	77
160	6	69	69	69	69	68	69	68	69	76	75	75	76	75	76	76	75	75
200	7	64	65	64	64	68	70	69	69	74	75	74	74	74	74	74	75	75
250	8	63	64	65	66	76	77	76	75	76	76	76	77	76	78	73	78	77
320	9	63	67	73	74	75	75	74	74	78	78	78	79	78	79	79	79	79
400	10	77	84	88	90	72	73	74	74	83	83	82	82	83	84	84	84	84
500	11	71	86	91	94	69	91	73	76	79	80	80	80	81	81	82	82	83
630	12	54	64	70	73	66	67	69	69	78	78	78	78	79	79	79	80	80
800	13	58	57	61	63	74	74	73	76	75	76	79	80	82	84	85	84	87
1000	14	52	54	57	60	71	70	69	74	73	74	76	77	79	80	81	81	82
1250	15	49	56	55	57	64	65	66	68	76	76	77	78	79	80	80	80	81
1600	16	50	51	52	52	65	65	66	67	78	76	77	79	81	81	81	79	80
2000	17	40	43	44	46	60	62	64	67	73	74	74	74	73	74	76	77	79
2500	18	39	41	40	42	58	59	59	61	72	73	73	72	72	73	74	74	75
3200	19	39	38	38	37	54	53	54	55	72	71	71	71	71	71	71	72	72
4000	20	40	39	41	40	51	52	52	52	70	70	71	70	70	70	71	70	70
5000	21	40	39	40	39	51	51	52	52	66	66	67	67	67	67	67	67	67
6300	22	41	41	40	40	52	51	52	53	66	66	66	66	65	65	65	65	65
8000	23	37	37	37	36	49	48	50	49	63	63	62	62	63	62	62	62	62
10000	24	31	31	32	31	46	47	49	47	60	59	58	58	60	59	59	59	58

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4. Effect of Windscreen on Microphone

$$A_{\frac{1}{2}}, n = 3450 \text{ RPM}$$

f	Band	Ambient	<u>SPL</u>	
			No Screen	With Screen
100	4	57	78	77
125	5	52	76	76
160	6	57	76	75
200	7	51	75	73
250	8	48	77	76
320	9	50	78	78
400	10	50	83	83
500	11	42	79	79
630	12	40	78	77
800	13	46	77	75
1000	14	41	74	73
1250	15	38	77	76
1600	16	40	78	76
2000	17	37	76	73
2500	18	37	75	72
3200	19	33	76	71
4000	20	26	74	70
5000	21	19	69	67
6300	22	19	67	66
8000	23	19	66	63
10000	24	19	63	60

TABLE 1. SUMMARY OF RESULTS

$$N = 2450 \text{ km}^2$$

Year	Area	Population	Urban
1900	4	21	18
1910	5	22	19
1920	6	23	20
1930	7	24	21
1940	8	25	22
1950	9	26	23
1960	10	27	24
1970	11	28	25
1980	12	29	26
1990	13	30	27
2000	14	31	28
2010	15	32	29
2020	16	33	30
2030	17	34	31
2040	18	35	32
2050	19	36	33
2060	20	37	34
2070	21	38	35
2080	22	39	36
2090	23	40	37
2100	24	41	38

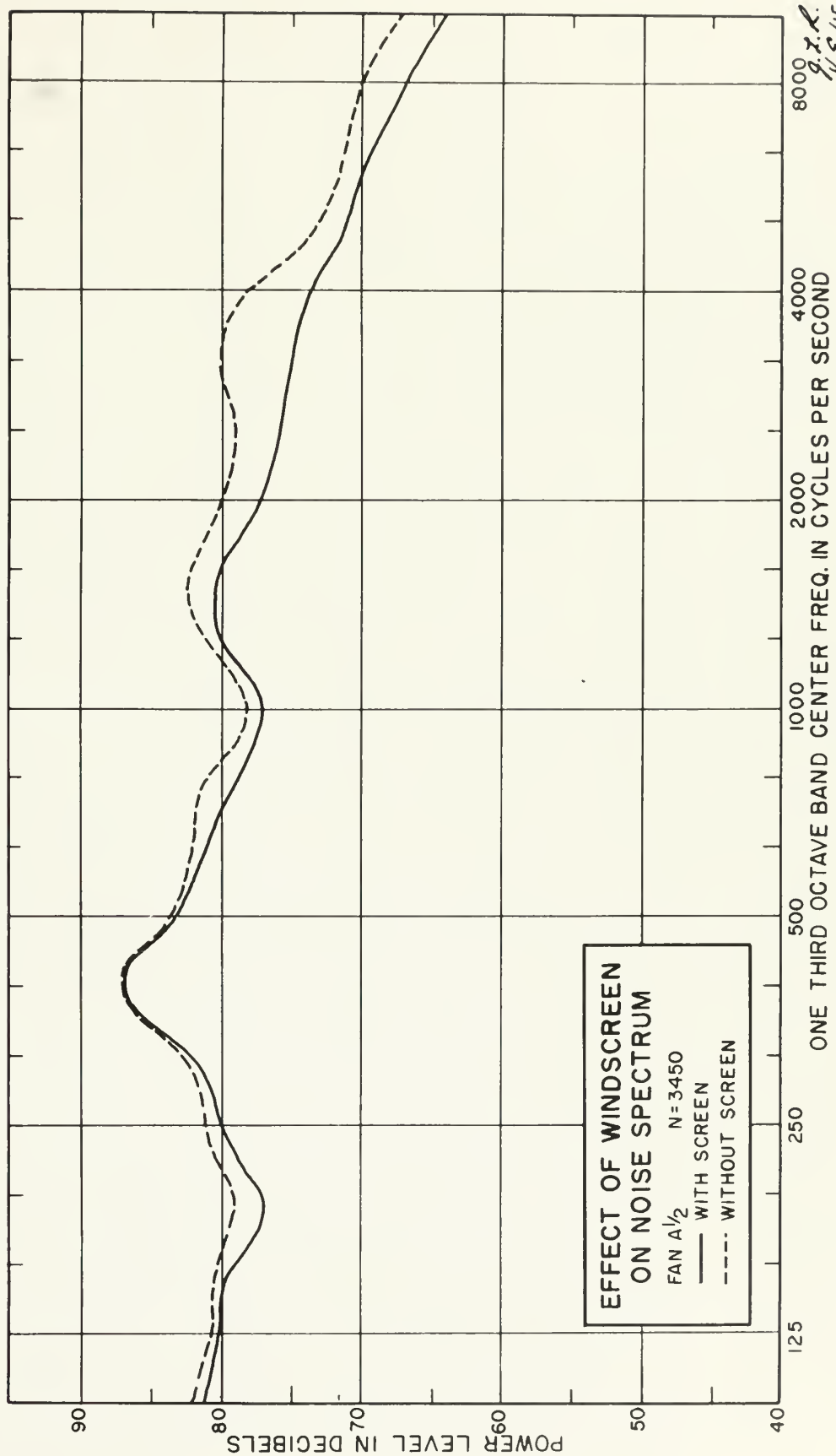


FIGURE 9

g.z.k.  
K.E.W.  
5/9/52



5.

A<sub>2</sub><sup>1</sup> Fan Test (No Back Pressure)

Band Center Freq.	Band No.	Spectrum Level Corr.	Ambient	n = 800		900		1000	
				SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	4	12.5	57	65	51.5	68	55.5	66	53.5
125	5	15	52	66	51	64	49	63	48
160	6	16	57	63	46	73	57	69	53
200	7	16.5	51	58	40.5	61	44.5	64	47.5
250	8	17.5	48	60	42.5	62	44.5	63	45.5
320	9	18.5	50	73	54.5	72	53.5	63	44.5
400	10	19.5	50	71	51.5	83	63.5	77	57.5
500	11	21	42	58	37	69	48	71	50
630	12	22	40	52	30	57	35	54	32
800	13	23	46	52	28	57	34	58	35
1000	14	24	41	54	30	56	32	52	28
1250	15	25	38	48	23	57	32	49	24
1600	16	26	40	48	21	56	30	50	24
2000	17	27	37	41	12	45	17	42	13
2500	18	28	37	40	9	40	9	41	11
3200	19	29	33	37	6	39	9	40	10
4000	20	30	26	36	6	38	8	40	10
5000	21	30.5	19	38	7.5	39	8.5	40	9.5
6300	22	31	19	39	8	40	9	41	10
8000	23	31.5	19	34	2.5	36	4.5	37	5.5
10000	24	32	19	28	- 4	31	- 1	31	- 1
Overall SPL 0" (On Duct $\phi$ )				82		79		81	
3"				80		89		88	
6"				81		88		93	
8"				82.5		91		95	
Average Overall SPL				81.8		87.7		90.8	

1/5 Fan Test (No Back Pressure)

2.

Band Center Freq.	Band No.	Frequency Level Cort.	Amplitude	n = 800 SPL Level	900 SPL Level	1000 SPL Level
100	4	15.5	27	62	68	23.5
125	5	15	25	66	64	48
160	6	16	27	61	73	53
200	7	16.5	21	55	61	47.5
250	8	17.5	48	60	62	45.2
320	9	18.5	20	73	75	44.2
400	10	19.5	20	71	83	27.5
500	11	21	48	50	66	20
630	12	22	40	55	57	35
800	13	23	46	55	57	35
1000	14	24	41	54	56	35
1250	15	25	38	48	57	34
1600	16	26	40	48	56	34
2000	17	27	37	41	45	13
2500	18	28	27	40	40	11
3200	19	29	23	37	39	10
4000	20	30	26	36	38	10
5000	21	30.5	19	35	39	9.5
6300	22	31	19	39	40	10
8000	23	31.5	19	34	36	5.5
10000	24	32	18	38	31	1

Overall SPL 0" (on axis)  $\phi$

8" 65.5

6" 81

3" 58

12" 78

Average Overall SPL 61.8

A-12  
 $\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 1100		1200		1300		1500	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	66	53.5	65	51.5	70	57.5	68	55.5
125	66	51	66	51	64	49	66	51
160	64	47	68	52	69	53	68	52
200	64	47.5	62	45.5	66	49.5	67	50.5
250	64	46.5	64	46.5	68	50.5	72	54.5
320	64	45.5	67	48.5	67	48.5	69	50.5
400	73	53.5	66	46.5	63	43.5	68	48.5
500	82	61	74	53	74	53	64	43
630	68	46	61	39	77	55	66	44
800	58	35	56	33	59	36	60	37
1000	57	33	64	40	56	32	58	34
1250	53	28	57	32	56	31	58	33
1600	52	26	59	33	58	32	60	34
2000	45	17	49	22	49	22	53	26
2500	42	12	46	18	44	16	50	22
3200	42	13	43	14	43	14	46	17
4000	41	11	42	12	43	13	45	15
5000	44	13.5	43	12.5	44	13.5	47	16.5
6300	42	11	44	13	44	13	46	15
8000	40	8.5	42	11.5	41	9.5	43	11.5
10000	36	4	37	5	38	6	40	8
Overall								
SPL	0"	85		79		81		82
	3"	92		82		81		84
	6"	97		89		84		89
	8"	98		92		85		90
Average Overall								
	SL	92.0		87.0		83.0		86.8

Band Center Freq	1100 1100 Level	1100 1100 Level	1100 1100 Level	1100 1100 Level	1100 1100 Level	1100 1100 Level
100	65	23.2	65	23.2	70	27.3
115	66	21	66	21	68	42
130	68	17	68	17	69	23
150	68	17.3	68	17.3	68	40.2
170	68	16.2	68	16.2	68	20.2
190	68	15.2	67	16.2	67	15.2
210	73	23.2	68	16.2	67	17.2
230	82	21	74	23	74	23
250	83	16	81	20	77	23
270	88	36	86	23	82	36
290	87	23	84	40	86	35
310	88	16	87	28	86	21
330	88	21	88	23	88	20
350	88	17	88	25	88	23
370	88	15	86	18	84	16
390	88	13	83	14	83	14
410	81	13	83	15	83	13
430	88	13.2	83	15.2	84	17.2
450	88	11	86	13	84	13
470	88	8.2	86	11.2	87	2.2
1000	38	4	27	2	28	8

Overall	Overall	Overall	Overall
87.0	87.0	87.0	87.0
87.0	87.0	87.0	87.0
87.0	87.0	87.0	87.0

$A\frac{1}{2}$  Pan Test (No Back Pressure)

Band Center Freq	n = 1700		2000		2300		2600	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	81	68.5	75	62.5	71	58.5	79	66.5
125	68	53	71	56	70	55	73	58
160	68	52	68	52	71	55	71	55
200	70	53.5	68	51.5	70	53.5	69	52.5
250	71	53.5	76	58.5	79	61.5	74	56.5
320	75	56.5	75	56.5	77	58.5	81	62.5
400	70	50.5	72	52.5	74	54.5	74	54.5
500	64	43	69	48	75	54	76	55
630	64	42	66	44	69	47	73	51
800	67	44	74	51	68	45	69	46
1000	59	35	71	47	71	47	73	49
1250	60	35	64	39	66	41	72	47
1600	62	36	65	39	68	42	71	45
2000	56	29	60	33	64	37	66	39
2500	51	23	58	30	62	34	66	38
3200	49	20	54	25	59	30	63	34
4000	47	17	51	21	56	26	61	31
5000	46	15.5	51	20.5	53	22.5	58	27.5
6300	48	17	52	21	54	23	58	27
8000	46	14.5	49	17.5	50	18.5	60	28.5
10000	42	10	46	14	47	15	58	26
<hr/>								
Overall SPL 0"	86		86		87		90	
3"	86		86		88		91	
6"	88		86		89		92	
8"	88		87		89		92	
<hr/>								
Average Ov. SPL	87.0		86.2		88.3		91.3	

$\frac{1}{2}$  sec. (10 sec. intervals)

Band Center Freq	$\lambda = 1750$		$\lambda = 2000$		$\lambda = 2500$		$\lambda = 3000$	
	FWHM Level	FWHM Level	FWHM Level	FWHM Level	FWHM Level	FWHM Level	FWHM Level	FWHM Level
100	81	68.5	79	66.5	71	58.5	73	55.5
125	68	55	71	58	70	52	73	53
150	68	55	71	58	71	52	71	52
200	70	52.5	68	51.5	70	52.5	69	54.5
250	71	52.5	70	50.5	70	51.5	74	56.5
300	72	56.5	72	56.5	72	56.5	71	62.5
400	70	50.5	72	58.5	70	54.5	74	54.5
500	67	43	63	48	72	54	70	63
625	66	48	62	44	69	47	72	61
800	67	44	74	51	68	43	69	54
1000	59	35	71	47	71	47	72	49
1250	60	35	67	39	66	41	72	47
1500	63	36	62	39	68	42	71	45
2000	56	29	60	33	64	37	66	39
2500	51	23	58	30	62	34	65	36
3000	49	20	54	28	60	30	62	34
4000	47	19	51	21	56	26	61	27
5000	46	15.5	51	20.5	53	23.5	59	21.5
6300	45	17	56	24	54	23	58	21
8000	46	14.5	49	17.5	50	19.5	60	19.5
10000	43	10	46	14	47	12	60	16

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0.4 sec.  
0.5 sec.

$\frac{1}{A_2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 3000		3200		3450	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	79	66.5	79	66.5	78	65.5
125	73	58	78	63	77	62
160	74	58	74	58	75	59
200	72	55.5	73	56.5	74	57.5
250	75	57.5	76	58.5	77	59.5
320	78	59.5	79	60.5	78	59.5
400	80	60.5	83	63.5	83	63.5
500	78	57	78	57	79	58
630	77	55	77	55	78	56
800	73	50	76	53	75	52
1000	74	50	73	49	73	49
1250	75	50	76	52	76	51
1600	73	47	75	49	78	52
2000	70	43	72	45	73	46
2500	71	43	70	42	72	44
3200	68	39	70	41	72	43
4000	66	36	68	38	70	40
5000	62	31.5	65	34.5	66	35.5
6300	62	31	66	35	66	35
8000	64	32.5	65	33.5	63	31.5
10000	62	30	62	30	60	28
Overall						
SPL	0"	92	92		93.5	
	3"	93	93		95	
	6"	94	94		95	
	8"	95	95		96	
Average						
OV. SPL		93.6	93.6		95.0	



6.

A<sub>2</sub><sup>1</sup> Fan Test (With Back Pressure)

Band Center Freq	n = 1000		1500		2000	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	65	52.5	68	55.5	73	60.5
125	63	48	64	49	70	55
160	70	54	66	50	67	51
200	67	50.5	67	50.5	67	50.5
250	62	44.5	74	46.5	76	58.5
320	62	43.5	68	49.5	75	56.5
400	73	53.5	67	47.5	73	53.5
500	69	48	62	41	67	46
630	54	32	65	43	65	43
800	67	44	59	36	76	53
1000	64	40	58	34	73	49
1250	54	29	58	33	63	38
1600	53	27	60	34	64	38
2000	49	22	54	27	60	33
2500	46	18	52	24	58	30
3200	44	15	50	21	54	25
4000	40	10	49	19	52	22
5000	39	8.5	48	17.5	52	21.5
6300	43	12	50	19	53	22
8000	40	8.5	47	15.5	54	22.5
10000	32	0	44	12	54	22
<hr/>						
Overall						
SPL 0"		81		82		85
3"		87.5		83		85
6"		93.5		85		86
8"		94		87		86
<hr/>						
Average						
OV. SPL		90.4		85.0		85.5
<hr/>						
Back Pressure		.06		.10		.16
inches of H <sub>2</sub> O						

(continued from page 193)

Depth feet	1000 - 1500 feet		1500 - 2000 feet		2000 - 2500 feet		Depth feet
	1000 feet	1500 feet	1500 feet	2000 feet	2000 feet	2500 feet	
1000	20	18	18	18	18	18	1000
1100	20	18	18	18	18	18	1100
1200	20	18	18	18	18	18	1200
1300	20	18	18	18	18	18	1300
1400	20	18	18	18	18	18	1400
1500	20	18	18	18	18	18	1500
1600	20	18	18	18	18	18	1600
1700	20	18	18	18	18	18	1700
1800	20	18	18	18	18	18	1800
1900	20	18	18	18	18	18	1900
2000	20	18	18	18	18	18	2000
2100	20	18	18	18	18	18	2100
2200	20	18	18	18	18	18	2200
2300	20	18	18	18	18	18	2300
2400	20	18	18	18	18	18	2400
2500	20	18	18	18	18	18	2500
2600	20	18	18	18	18	18	2600
2700	20	18	18	18	18	18	2700
2800	20	18	18	18	18	18	2800
2900	20	18	18	18	18	18	2900
3000	20	18	18	18	18	18	3000
3100	20	18	18	18	18	18	3100
3200	20	18	18	18	18	18	3200
3300	20	18	18	18	18	18	3300
3400	20	18	18	18	18	18	3400
3500	20	18	18	18	18	18	3500
3600	20	18	18	18	18	18	3600
3700	20	18	18	18	18	18	3700
3800	20	18	18	18	18	18	3800
3900	20	18	18	18	18	18	3900
4000	20	18	18	18	18	18	4000
4100	20	18	18	18	18	18	4100
4200	20	18	18	18	18	18	4200
4300	20	18	18	18	18	18	4300
4400	20	18	18	18	18	18	4400
4500	20	18	18	18	18	18	4500
4600	20	18	18	18	18	18	4600
4700	20	18	18	18	18	18	4700
4800	20	18	18	18	18	18	4800
4900	20	18	18	18	18	18	4900
5000	20	18	18	18	18	18	5000
5100	20	18	18	18	18	18	5100
5200	20	18	18	18	18	18	5200
5300	20	18	18	18	18	18	5300
5400	20	18	18	18	18	18	5400
5500	20	18	18	18	18	18	5500
5600	20	18	18	18	18	18	5600
5700	20	18	18	18	18	18	5700
5800	20	18	18	18	18	18	5800
5900	20	18	18	18	18	18	5900
6000	20	18	18	18	18	18	6000
6100	20	18	18	18	18	18	6100
6200	20	18	18	18	18	18	6200
6300	20	18	18	18	18	18	6300
6400	20	18	18	18	18	18	6400
6500	20	18	18	18	18	18	6500
6600	20	18	18	18	18	18	6600
6700	20	18	18	18	18	18	6700
6800	20	18	18	18	18	18	6800
6900	20	18	18	18	18	18	6900
7000	20	18	18	18	18	18	7000
7100	20	18	18	18	18	18	7100
7200	20	18	18	18	18	18	7200
7300	20	18	18	18	18	18	7300
7400	20	18	18	18	18	18	7400
7500	20	18	18	18	18	18	7500
7600	20	18	18	18	18	18	7600
7700	20	18	18	18	18	18	7700
7800	20	18	18	18	18	18	7800
7900	20	18	18	18	18	18	7900
8000	20	18	18	18	18	18	8000
8100	20	18	18	18	18	18	8100
8200	20	18	18	18	18	18	8200
8300	20	18	18	18	18	18	8300
8400	20	18	18	18	18	18	8400
8500	20	18	18	18	18	18	8500
8600	20	18	18	18	18	18	8600
8700	20	18	18	18	18	18	8700
8800	20	18	18	18	18	18	8800
8900	20	18	18	18	18	18	8900
9000	20	18	18	18	18	18	9000
9100	20	18	18	18	18	18	9100
9200	20	18	18	18	18	18	9200
9300	20	18	18	18	18	18	9300
9400	20	18	18	18	18	18	9400
9500	20	18	18	18	18	18	9500
9600	20	18	18	18	18	18	9600
9700	20	18	18	18	18	18	9700
9800	20	18	18	18	18	18	9800
9900	20	18	18	18	18	18	9900
10000	20	18	18	18	18	18	10000

Block thickness  
inches of 100

100 100 100 100

Average  
of 100

100 100 100 100

$A\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq	n = 2500		3000		3450	
	SPL	Spec Level	SPL	Spec. Level	SPL	Spec Level
100	74	61.5	75	62.5	75	62.5
125	76	61	71	56	74	59
160	71	55	72	56	73	57
200	69	52.5	69	52.5	72	55.5
250	74	56.5	75	57.5	75	57.5
320	79	60.5	78	59.5	76	57.5
400	73	53.5	83	63.5	81	61.5
500	74	53	79	58	78	57
630	70	48	79	57	78	56
800	68	45	73	50	81	58
1000	79	55	74	50	76	52
1250	72	47	74	49	77	52
1600	69	43	72	46	79	53
2000	66	39	69	42	73	46
2500	64	36	69	41	72	44
3200	62	33	68	39	72	43
4000	58	28	64	34	69	39
5000	54	23.5	60	29.5	64	33.5
6300	57	26	61	30	65	34
8000	58	26.5	62	30.5	63	31.5
10000	57	25	60	28	60	28
Overall						
SPL	0"	87.5	91		93.5	
	3"	88	92		94	
	6"	89	94		94	
	8"	89	95		94	
Average						
OV. SPL		88.3	93.2		93.9	
Back Pressure						
Inches of H <sub>2</sub> O		.21	.275		.325	

Back Pressure Pounds per sq. in.	Flow Rate			Pressure			Flow Rate
	0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0	0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0	0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0	0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0	0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0	0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0	
1000	10.0	10.0	10.0	10.0	10.0	10.0	10.0
800	9.5	9.5	9.5	9.5	9.5	9.5	9.5
600	9.0	9.0	9.0	9.0	9.0	9.0	9.0
400	8.5	8.5	8.5	8.5	8.5	8.5	8.5
200	8.0	8.0	8.0	8.0	8.0	8.0	8.0
100	7.5	7.5	7.5	7.5	7.5	7.5	7.5
50	7.0	7.0	7.0	7.0	7.0	7.0	7.0
25	6.5	6.5	6.5	6.5	6.5	6.5	6.5
10	6.0	6.0	6.0	6.0	6.0	6.0	6.0
5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
2	5.0	5.0	5.0	5.0	5.0	5.0	5.0
1	4.5	4.5	4.5	4.5	4.5	4.5	4.5
0.5	4.0	4.0	4.0	4.0	4.0	4.0	4.0
0.2	3.5	3.5	3.5	3.5	3.5	3.5	3.5
0.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0
0.05	2.5	2.5	2.5	2.5	2.5	2.5	2.5
0.02	2.0	2.0	2.0	2.0	2.0	2.0	2.0
0.01	1.5	1.5	1.5	1.5	1.5	1.5	1.5
0.005	1.0	1.0	1.0	1.0	1.0	1.0	1.0
0.002	0.5	0.5	0.5	0.5	0.5	0.5	0.5
0.001	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Overall SPL Data at Other Speeds

$\frac{1}{A_2}$ , With Back Pressure - Ambient SPL = 82

	n	800	900	1100	1200	1300	1800	2200
Overall SPL								
0"	84	85	85	85.5	85	86	87	
3"	85	95.5	87	87.5	86	86.5	87.5	
6"	86.5	100.5	89	89	90	89.5	88.5	
8"	87.5	96.5	90.5	89	92	91.5	90	
Overall SPL Corr. for Ambient								
0"	79.5	82	82	83	82	84	85.5	
3"	82	95.5	85.5	86	84	84.5	86	
6"	84.5	100.5	88	88	89	88.5	87.5	
8"	86	96.5	90	88	91.5	91.0	90	
Av. OV. SPL		83.3	95.6	86.8	86.5	87.4	87.4	87.4
Back Press. in. of H <sub>2</sub> O		.045	.05	.07	.08	.09	.13	.18



7.

A1 $\frac{1}{2}$  Fan Test, (No Back Pressure)

Band Center Freq	Band No.	Spectrum Level Corr.	Ambient	n = 800		900		1000	
				SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	4	12.5	61	81	69.5	72	59.5	71	58.5
125	5	15	56	70	45	68	53	70	55
160	6	16	56	65	49	65	49	66	51
200	7	16.5	52	63	46.5	65	48.5	65	48.5
250	8	17.5	48	64	46.5	66	48.5	66	48.5
320	9	18.5	49	66	47.5	64	45.5	64	45.5
400	10	19.5	50	59	39.5	60	40.5	62	42.5
500	11	21	43	61	40.0	58	37	61	40
630	12	22	40	53	31	54	32	56	34
800	13	23	46	54	31	56	33	56	33
1000	14	24	42	58	34	59	35	61	37
1250	15	25	40	56	31	59	34	60	35
1600	16	26	41	55	29	58	32	60	34
2000	17	27	40	50	23	53	26	55	28
2500	18	28	42	46	18	47	19	48	20
3200	19	29	37	44	15	48	13	49	20
4000	20	30	34	45	15	46	16	48	18
5000	21	30.5	29	40	9.5	40	9.5	40	9.5
6300	22	31	26	35	4	37	6	36	5
8000	23	31.5	26	33	1.5	35	3.5	36	4.5
10000	24	32	20	32	0	33	1	34	2
Overall SPL				0"	82	82		81	
				3"	84	81		82	
				6"	84	82		83	
				8"	85	83		84	
Average Overall SPL			73.0	83.8		82		82.5	
Current (amps)					2.4	2.42		2.43	
Voltage					14.2	15.1		16.9	

$\frac{1}{2}$  inch (No. 1000)

7.

Overall		Overall		Overall		Overall		Overall	
No.		No.		No.		No.		No.	
1000	10	900	10	800	10	700	10	600	10
900	10	800	10	700	10	600	10	500	10
800	10	700	10	600	10	500	10	400	10
700	10	600	10	500	10	400	10	300	10
600	10	500	10	400	10	300	10	200	10
500	10	400	10	300	10	200	10	100	10
400	10	300	10	200	10	100	10	0	10
300	10	200	10	100	10	0	10		
200	10	100	10	0	10				
100	10	0	10						
0	10								

Overall		Overall		Overall		Overall		Overall	
No.		No.		No.		No.		No.	
1000	10	900	10	800	10	700	10	600	10
900	10	800	10	700	10	600	10	500	10
800	10	700	10	600	10	500	10	400	10
700	10	600	10	500	10	400	10	300	10
600	10	500	10	400	10	300	10	200	10
500	10	400	10	300	10	200	10	100	10
400	10	300	10	200	10	100	10	0	10
300	10	200	10	100	10	0	10		
200	10	100	10	0	10				
100	10	0	10						
0	10								

$Al\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 1100		1200		1300		1500	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	72	59.5	75	62.5	78	65.5	79	66.5
125	73	58	73	58	73	58	72	57
160	68	52	70	54	73	57	75	59
200	66	49.5	67	50.5	67	50.5	69	52.5
250	68	50.5	70	52.5	69	51.5	71	53.5
320	65	46.5	68	49.5	68	49.5	71	52.5
400	65	45.5	65	45.5	65	45.5	66	46.5
500	61	40	62	41	63	42	68	47
630	57	45	59	37	60	38	62	41
800	58	45	59	36	59	36	62	40
1000	63	39	62	38	64	40	65	42
1250	60	35	61	36	62	37	65	40
1600	60	34	62	36	63	37	65	39
2000	58	31	59	32	61	34	64	37
2500	50	22	52	24	53	25	58	30
3200	51	22	53	24	53	24	54	25
4000	49	19	50	20	51	21	53	23
5000	42	11.5	43	12.5	45	14.5	47	16.5
6300	38	7	39	8	40	9	43	12
8000	37	5.5	37	5.5	39	7.5	42	10.5
10000	35	3	34.5	2.5	35	3	37	5

## Overall SPL

0"	84	84	84.5	86
3"	84.5	84	85	86
6"	85	83.5	85	86
8"	85	83.5	86	87
Aver. Ov. SPL	84.7	83.8	85.2	86.2

Current (amps) 2.44  
Voltage 18.2

2.55  
19.5

2.6  
21.0

2.78  
24.3



$Al\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 1700		2000		2300		2500	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	75	67.5	82	62.5	76	63.5	80	67.5
125	73	58	75	60	75	60	79	64
160	73	57	74	58	75	59	75	59
200	74	57.5	73	56.5	74	57.5	74	57.5
250	72	54.5	74	56.5	79	61.5	82	63.5
320	72	53.5	74	55.5	76	57.5	78	59.5
400	70	50.5	72	52.5	75	55.5	75	55.5
500	68	47	68	47	72	51	74	53
630	65	43	69	47	71	49	71	49
800	64	41	68	45	71	48	72	49
1000	68	34	74	50	74	50	77	53
1250	68	33	73	48	75	50	77	52
1600	65	39	69	43	71	45	73	47
2000	66	39	69	42	71	44	74	47
2500	63	35	68	40	70	42	73	45
3200	58	29	64	35	69	40	73	44
4000	56	26	60	30	67	37	72	42
5000	50	19.5	55	24.5	59	28.5	65	34.5
6300	47	16	52	21	55	24	60	29
8000	45	14.5	50	18.5	54	22.5	58	26.5
10000	40	8	44	12	48	16	53	21

## Overall SPL

0"	86.5	92	92.5	93
3"	86.5	92	93	92.5
6"	86.5	91.5	93	93
8"	87	91.5	93	93
Average Overall SPL	86.6	91.8	92.9	92.9

Current (amps)	2.9	3.05	3.4	3.55
Voltage	27.9	33.3	39.9	45.9

# $\frac{1}{2}$ in. Grit (No. 20) (continued)

Sand Control Type	n = 1700		6000		1300		2500	
	ASTM No. 20	ASTM No. 20	ASTM No. 20	ASTM No. 20	ASTM No. 20	ASTM No. 20	ASTM No. 20	ASTM No. 20
100	75	67.5	68	65.5	70	67.5	50	67.5
125	75	58	70	60	75	60	70	64
150	75	59	74	58	75	59	70	50
200	74	57.5	73	50.5	74	57.5	74	57.5
250	75	54.5	74	54.5	75	61.5	60	53.5
300	74	53.5	74	53.5	76	57.5	70	53.5
400	70	50.5	74	50.5	75	55.5	75	52.5
500	68	47	65	47	74	51	74	53
630	65	43	63	47	71	49	73	49
800	64	41	60	45	71	46	73	49
1000	60	34	54	50	74	50	77	53
1250	63	33	73	48	75	50	77	50
1600	64	38	60	43	71	49	73	47
2000	66	39	60	40	71	44	74	47
2500	63	37	68	40	70	42	73	49
3000	58	50	64	35	69	40	73	44
4000	56	55	60	30	67	37	70	46
5000	50	49.5	55	64.5	50	60.5	65	54.5
6300	47	46	54	57	50	61	60	50
8000	45	44.5	50	40.5	54	58.5	50	50.5
10000	40	4	44	14	48	54	50	57

Overall 1700

Average Overall 1700	Overall 6000	Overall 1300	Overall 2500
64.5	61.5	67.5	65.5
50.5	54.5	57.5	55.5
40.5	40.5	40.5	40.5
34.5	34.5	34.5	34.5
24.5	24.5	24.5	24.5
14.5	14.5	14.5	14.5
4.5	4.5	4.5	4.5

Control (avg) 57.5  
Volids 39.5  
3.50  
57.5

$Al\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 2600		3000		3200		3450	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	78	65.5	85	72.5	98	85.5	87	74.5
125	77	62	83	68	87	72	80	65
160	77	61	77	61	80	64	79	63
200	76	59.5	76	59.5	78	61.5	78	61.5
250	80	62.5	78	60.5	79	61.5	80	62.5
320	78	59.5	79	60.5	80	61.5	81	62.5
400	75	55.5	77	57.5	79	59.5	83	63.5
500	74	53	76	55	78	57	82	61
630	71	49	74	52	77	55	79	57
800	72	49	74	51	76	53	78	55
1000	76	52	79	55	81	57	84	60
1250	77	52	79	54	80	55	82	57
1600	73	47	78	52	78	52	79	53
2000	72	45	76	49	77	50	78	51
2500	70	42	73	45	74	46	76	48
3200	70	41	72	43	73	44	74	45
4000	70	40	75	45	76	46	77	47
5000	63	32.5	70	39.5	73	42.5	76	45.5
6300	59	28	63	32	66	35	70	39
8000	56	24.5	61	29.5	63	31.5	65	33.5
10000	52	20	56	24	58	26	61	29
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Overall	SPL							
	0"	92.5	94		102		97	
	3"	92.5	94		102		97	
	6"	92.5	95		102		96	
Average	8"	93	96		102		96	
	Overall SPL	92.6	94.8		102		96.5	
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Current (amps)		3.76	4.04		4.25		4.6	
Voltage		48.8	55		60		70	

Year	1900		1901		1902		1903		1904		1905		1906		1907		1908		1909		1910		1911		1912		1913		1914		1915		1916		1917		1918		1919		1920		1921		1922		1923		1924		1925		1926		1927		1928		1929		1930		1931		1932		1933		1934		1935		1936		1937		1938		1939		1940		1941		1942		1943		1944		1945		1946		1947		1948		1949		1950		1951		1952		1953		1954		1955		1956		1957		1958		1959		1960		1961		1962		1963		1964		1965		1966		1967		1968		1969		1970		1971		1972		1973		1974		1975		1976		1977		1978		1979		1980		1981		1982		1983		1984		1985		1986		1987		1988		1989		1990		1991		1992		1993		1994		1995		1996		1997		1998		1999		2000		2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		2016		2017		2018		2019		2020		2021		2022		2023		2024		2025		2026		2027		2028		2029		2030		2031		2032		2033		2034		2035		2036		2037		2038		2039		2040		2041		2042		2043		2044		2045		2046		2047		2048		2049		2050		2051		2052		2053		2054		2055		2056		2057		2058		2059		2060		2061		2062		2063		2064		2065		2066		2067		2068		2069		2070		2071		2072		2073		2074		2075		2076		2077		2078		2079		2080		2081		2082		2083		2084		2085		2086		2087		2088		2089		2090		2091		2092		2093		2094		2095		2096		2097		2098		2099		2100		2101		2102		2103		2104		2105		2106		2107		2108		2109		2110		2111		2112		2113		2114		2115		2116		2117		2118		2119		2120		2121		2122		2123		2124		2125		2126		2127		2128		2129		2130		2131		2132		2133		2134		2135		2136		2137		2138		2139		2140		2141		2142		2143		2144		2145		2146		2147		2148		2149		2150		2151		2152		2153		2154		2155		2156		2157		2158		2159		2160		2161		2162		2163		2164		2165		2166		2167		2168		2169		2170		2171		2172		2173		2174		2175		2176		2177		2178		2179		2180		2181		2182		2183		2184		2185		2186		2187		2188		2189		2190		2191		2192		2193		2194		2195		2196		2197		2198		2199		2200		2201		2202		2203		2204		2205		2206		2207		2208		2209		2210		2211		2212		2213		2214		2215		2216		2217		2218		2219		2220		2221		2222		2223		2224		2225		2226		2227		2228		2229		2230		2231		2232		2233		2234		2235		2236		2237		2238		2239		2240		2241		2242		2243		2244		2245		2246		2247		2248		2249		2250		2251		2252		2253		2254		2255		2256		2257		2258		2259		2260		2261		2262		2263		2264		2265		2266		2267		2268		2269		2270		2271		2272		2273		2274		2275		2276		2277		2278		2279		2280		2281		2282		2283		2284		2285		2286		2287		2288		2289		2290		2291		2292		2293		2294		2295		2296		2297		2298		2299		2300		2301		2302		2303		2304		2305		2306		2307		2308		2309		2310		2311		2312		2313		2314		2315		2316		2317		2318		2319		2320		2321		2322		2323		2324		2325		2326		2327		2328		2329		2330		2331		2332		2333		2334		2335		2336		2337		2338		2339		2340		2341		2342		2343		2344		2345		2346		2347		2348		2349		2350		2351		2352		2353		2354		2355		2356		2357		2358		2359		2360		2361		2362		2363		2364		2365		2366		2367		2368		2369		2370		2371		2372		2373		2374		2375		2376		2377		2378		2379		2380		2381		2382		2383		2384		2385		2386		2387		2388		2389		2390		2391		2392		2393		2394		2395		2396		2397		2398		2399		2400		2401		2402		2403		2404		2405		2406		2407		2408		2409		2410		2411		2412		2413		2414		2415		2416		2417		2418		2419		2420		2421		2422		2423		2424		2425		2426		2427		2428		2429		2430		2431		2432		2433		2434		2435		2436		2437		2438		2439		2440		2441		2442		2443		2444		2445		2446		2447		2448		2449		2450		2451		2452		2453		2454		2455		2456		2457		2458		2459		2460		2461		2462		2463		2464		2465		2466		2467		2468		2469		2470		2471		2472		2473		2474		2475		2476		2477		2478		2479		2480		2481		2482		2483		2484		2485		2486		2487		2488		2489		2490		2491		2492		2493		2494		2495		2496		2497		2498		2499		2500		2501		2502		2503		2504		2505		2506		2507		2508		2509		2510		2511		2512		2513		2514		2515		2516		2517		2518		2519		2520		2521		2522		2523		2524		2525		2526		2527		2528		2529		2530		2531		2532		2533		2534		2535		2536		2537		2538		2539		2540		2541		2542		2543		2544		2545		2546		2547		2548		2549		2550		2551		2552		2553		2554		2555		2556		2557		2558		2559		2560		2561		2562		2563		2564		2565		2566		2567		2568		2569		2570		2571		2572		2573		2574		2575		2576		2577		2578		2579		2580		2581		2582		2583		2584		2585		2586		2587		2588		2589		2590		2591		2592		2593		2594		2595		2596		2597		2598		2599		2600		2601		2602		2603		2604		2605		2606		2607		2608		2609		2610		2611		2612		2613		2614		2615		2616		2617		2618		2619		2620		2621		2622		2623		2624		2625		2626		2627		2628		2629		2630		2631		2632		2633		2634		2635		2636		2637		2638		2639		2640		2641		2642		2643		2644		2645		2646		2647		2648		2649		2650		2651		2652		2653		2654		2655		2656		2657		2658		2659		2660		2661		2662		2663		2664		2665		2666		2667		2668		2669		2670		2671		2672		2673		2674		2675		2676		2677		2678		2679		2680		2681		2682		2683		2684		2685		2686		2687		2688		2689		2690		2691		2692		2693		2694		2695		2696		2697		2698		2699		2700		2701		2702		2703		2704		2705		2706		2707		2708		2709		2710		2711		2712		2713		2714		2715		2716		2717		2718		2719		2720		2721		2722		2723		2724		2725		2726		2727		2728		2729		2730		2731		273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$A1\frac{1}{2}$  Fan Test (No Back Pressure)

Band Center Freq	n = 3800		4200		4600	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	84	71.5	81	68.5	81	68.5
125	82	67	83	68	83	68
160	80	64	80	64	81	65
200	78	61.5	79	62.5	80	63.5
250	81	63.5	81	63.5	81	63.5
320	79	60.5	82	63.5	82	63.5
400	81	61.5	83	63.5	82	62.5
500	81	60	82	61	86	65
630	80	58	81	59	83	61
800	80	57	82	59	83	60
1000	83	59	84	60	87	63
1250	83	58	85	60	88	63
1600	81	55	82	56	85	59
2000	80	53	82	55	83	56
2500	78	50	80	52	81	53
3200	75	46	78	49	79	50
4000	78	48	79	49	80	50
5000	78	47.5	79	48.5	80	49.5
6300	74	43	77	46	79	48
8000	69	37.5	73	41.5	76	44.5
10000	63	31	68	36	71	39

## Overall SPL

0"	97.5	99.5	100
3"	97	99.5	100.5
6"	97.5	100	101
8"	97.5	100	101.5
Average Overall SPL	97.4	99.8	100.8
Current (amps)	5.0	5.6	6.1
Voltage	78	90	104

Group	1st	2nd	3rd	4th	5th	6th
100	88	77	66	55	44	33
125	88	77	66	55	44	33
150	88	77	66	55	44	33
175	88	77	66	55	44	33
200	88	77	66	55	44	33
225	88	77	66	55	44	33
250	88	77	66	55	44	33
275	88	77	66	55	44	33
300	88	77	66	55	44	33
325	88	77	66	55	44	33
350	88	77	66	55	44	33
375	88	77	66	55	44	33
400	88	77	66	55	44	33
425	88	77	66	55	44	33
450	88	77	66	55	44	33
475	88	77	66	55	44	33
500	88	77	66	55	44	33
525	88	77	66	55	44	33
550	88	77	66	55	44	33
575	88	77	66	55	44	33
600	88	77	66	55	44	33
625	88	77	66	55	44	33
650	88	77	66	55	44	33
675	88	77	66	55	44	33
700	88	77	66	55	44	33
725	88	77	66	55	44	33
750	88	77	66	55	44	33
775	88	77	66	55	44	33
800	88	77	66	55	44	33
825	88	77	66	55	44	33
850	88	77	66	55	44	33
875	88	77	66	55	44	33
900	88	77	66	55	44	33
925	88	77	66	55	44	33
950	88	77	66	55	44	33
975	88	77	66	55	44	33
1000	88	77	66	55	44	33

Group	1st	2nd	3rd	4th	5th	6th
100	88	77	66	55	44	33
125	88	77	66	55	44	33
150	88	77	66	55	44	33
175	88	77	66	55	44	33
200	88	77	66	55	44	33
225	88	77	66	55	44	33
250	88	77	66	55	44	33
275	88	77	66	55	44	33
300	88	77	66	55	44	33
325	88	77	66	55	44	33
350	88	77	66	55	44	33
375	88	77	66	55	44	33
400	88	77	66	55	44	33
425	88	77	66	55	44	33
450	88	77	66	55	44	33
475	88	77	66	55	44	33
500	88	77	66	55	44	33
525	88	77	66	55	44	33
550	88	77	66	55	44	33
575	88	77	66	55	44	33
600	88	77	66	55	44	33
625	88	77	66	55	44	33
650	88	77	66	55	44	33
675	88	77	66	55	44	33
700	88	77	66	55	44	33
725	88	77	66	55	44	33
750	88	77	66	55	44	33
775	88	77	66	55	44	33
800	88	77	66	55	44	33
825	88	77	66	55	44	33
850	88	77	66	55	44	33
875	88	77	66	55	44	33
900	88	77	66	55	44	33
925	88	77	66	55	44	33
950	88	77	66	55	44	33
975	88	77	66	55	44	33
1000	88	77	66	55	44	33

8.

A1 $\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq	Band No.	Spectrum Level Corr.	Ambient	n = 800		900		1000	
				SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	4	12.5	60	76	63.5	75	62.5	75	62.5
125	5	15	55	67	52	68	53	70	55
160	6	16	50	65	49	62	46	63	47
200	7	16.5	47	59	42.5	62	45.5	61	44.5
250	8	17.5	44	60	42.5	62	44.5	64	46.5
320	9	18.5	41	59	40.5	60	41.5	61	42.5
400	10	19.5	50	55	35.5	57	37.5	59	39.5
500	11	21	40	59	38	59	38.0	59	38
630	12	22	35	51	29	55	33	55	33
800	13	23	40	51	28	52	29	55	32
1000	14	24	37	55	31	57	33	60	36
1250	15	25	33	53	28	55	30	58	33
1600	16	26	33	56	30	55	29	56	30
2000	17	27	30	48	21	51	24	52	25
2500	18	28	29	42	14	43	15	45	17
3200	19	29	35	43	14	45	16	47	18
4000	20	30	32	43.5	13.5	45	15	47	17
5000	21	30.5	28	38	7.5	39	8.5	40	9.5
6300	22	31	20	31	0	32.5	1.5	33	2
8000	23	31.5	20	32	0.5	33.5	2	35	3.5
10000	24	32	19	31	-1	33	1	34	2
Overall SPL				81		81		82	
				80.5		82		82	
				81		82		82	
				81		82		81	
Average Overall SPL				80.9		81.8		81.8	
Current (amps)				2.54		2.59		2.62	
Voltage				15		16.5		17.8	
Back Pressure				.09		.10		.12	

At the time of the 1980 census, the population of the city was 1,100.

Band Center Freq	Band No.	Frequency (MHz)	Power (dBm)	Power (dBm)	Power (dBm)	Power (dBm)	Power (dBm)
1000	24	10.0	-1	-1	-1	-1	-1
8000	23	8.0	-1	-1	-1	-1	-1
6000	22	6.0	-1	-1	-1	-1	-1
4000	21	4.0	-1	-1	-1	-1	-1
3500	20	3.5	-1	-1	-1	-1	-1
3000	19	3.0	-1	-1	-1	-1	-1
2500	18	2.5	-1	-1	-1	-1	-1
2000	17	2.0	-1	-1	-1	-1	-1
1800	16	1.8	-1	-1	-1	-1	-1
1600	15	1.6	-1	-1	-1	-1	-1
1400	14	1.4	-1	-1	-1	-1	-1
1200	13	1.2	-1	-1	-1	-1	-1
1000	12	1.0	-1	-1	-1	-1	-1
800	11	0.8	-1	-1	-1	-1	-1
600	10	0.6	-1	-1	-1	-1	-1
500	9	0.5	-1	-1	-1	-1	-1
400	8	0.4	-1	-1	-1	-1	-1
300	7	0.3	-1	-1	-1	-1	-1
200	6	0.2	-1	-1	-1	-1	-1
150	5	0.15	-1	-1	-1	-1	-1
100	4	0.1	-1	-1	-1	-1	-1
75	3	0.075	-1	-1	-1	-1	-1
50	2	0.05	-1	-1	-1	-1	-1
25	1	0.025	-1	-1	-1	-1	-1

$A1\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq.	n = 1100		1200		1300		1500	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	78	65.5	77	64.5	85	72.5	78	65.5
125	74	59	73	58	73	62	72	57
160	65	49	70	54	74	58	71	55
200	62	45.5	63	46.5	65	48.5	67	50.5
250	66	48.5	65	47.5	66	48.5	68	50.5
320	63	44.5	64	45.5	67	48.5	70	51.5
400	60	40.5	62	42.5	62	42.5	66	46.5
500	59	38	60	39	65	44	67	46
630	56	34	58	36	60	38	62	40
800	56	33	57	34	59	36	62	39
1000	61	37	61	37	63	39	65	41
1250	61	36	62	37	63	38	65	40
1600	60	34	64	38	64	38	64	36
2000	54	27	56	29	58	31	62	35
2500	47	19	50	22	51	23	55	27
3200	48.5	19.5	51	22	51	22	55	26
4000	48	18	51	21	51	21	54	24
5000	41	11.5	43	12.5	44	13.5	48	17.5
6300	35	4	37	6	38	7	42	11
8000	36	4.5	37	5.5	37.5	6	41.5	10
10000	36	4	37	5	36.5	3.5	39	7
Overall SPL								
	0"	82		88		90		85
	3"	83		87		90		85
	6"	83		86.5		91		85.5
	8"	82		87		90		85.5
Average Overall SPL								
		82.5		87.2		90.2		85.3
Current (amps)								
		2.71		2.79		2.85		3.0
Voltage								
		19.7		21.4		22.6		26.1
Back Pressure								
		.135		.15		.165		.195

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Band Center Freq.	B = 1100		B = 1200		B = 1300		B = 1400	
	Level	Int.	Level	Int.	Level	Int.	Level	Int.
100	10	02.5	10	02.5	10	02.5	10	02.5
105	10	02	10	02	10	02	10	02
110	10	02	10	02	10	02	10	02
115	10	02.5	10	02.5	10	02.5	10	02.5
120	10	02	10	02	10	02	10	02
125	10	02.5	10	02.5	10	02.5	10	02.5
130	10	02	10	02	10	02	10	02
135	10	02	10	02	10	02	10	02
140	10	02.5	10	02.5	10	02.5	10	02.5
145	10	02	10	02	10	02	10	02
150	10	02	10	02	10	02	10	02
155	10	02.5	10	02.5	10	02.5	10	02.5
160	10	02	10	02	10	02	10	02
165	10	02	10	02	10	02	10	02
170	10	02.5	10	02.5	10	02.5	10	02.5
175	10	02	10	02	10	02	10	02
180	10	02	10	02	10	02	10	02
185	10	02.5	10	02.5	10	02.5	10	02.5
190	10	02	10	02	10	02	10	02
195	10	02	10	02	10	02	10	02
200	10	02.5	10	02.5	10	02.5	10	02.5
205	10	02	10	02	10	02	10	02
210	10	02	10	02	10	02	10	02
215	10	02.5	10	02.5	10	02.5	10	02.5
220	10	02	10	02	10	02	10	02
225	10	02	10	02	10	02	10	02
230	10	02.5	10	02.5	10	02.5	10	02.5
235	10	02	10	02	10	02	10	02
240	10	02	10	02	10	02	10	02
245	10	02.5	10	02.5	10	02.5	10	02.5
250	10	02	10	02	10	02	10	02
255	10	02	10	02	10	02	10	02
260	10	02.5	10	02.5	10	02.5	10	02.5
265	10	02	10	02	10	02	10	02
270	10	02	10	02	10	02	10	02
275	10	02.5	10	02.5	10	02.5	10	02.5
280	10	02	10	02	10	02	10	02
285	10	02	10	02	10	02	10	02
290	10	02.5	10	02.5	10	02.5	10	02.5
295	10	02	10	02	10	02	10	02
300	10	02	10	02	10	02	10	02
305	10	02.5	10	02.5	10	02.5	10	02.5
310	10	02	10	02	10	02	10	02
315	10	02	10	02	10	02	10	02
320	10	02.5	10	02.5	10	02.5	10	02.5
325	10	02	10	02	10	02	10	02
330	10	02	10	02	10	02	10	02
335	10	02.5	10	02.5	10	02.5	10	02.5
340	10	02	10	02	10	02	10	02
345	10	02	10	02	10	02	10	02
350	10	02.5	10	02.5	10	02.5	10	02.5
355	10	02	10	02	10	02	10	02
360	10	02	10	02	10	02	10	02
365	10	02.5	10	02.5	10	02.5	10	02.5
370	10	02	10	02	10	02	10	02
375	10	02	10	02	10	02	10	02
380	10	02.5	10	02.5	10	02.5	10	02.5
385	10	02	10	02	10	02	10	02
390	10	02	10	02	10	02	10	02
395	10	02.5	10	02.5	10	02.5	10	02.5
400	10	02	10	02	10	02	10	02

Year	1970	1971	1972	1973	1974
Current (mm)	1.0	1.0	1.0	1.0	1.0
Wage	1.0	1.0	1.0	1.0	1.0
Profit	1.0	1.0	1.0	1.0	1.0
Overall	1.0	1.0	1.0	1.0	1.0

$Al\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq	n = 1700		2000		2300		2500	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	74	61.5	81	68.5	77	64.5	79	66.5
125	73	58	75	60	75	60	77	62
160	72	56	73	57	74	58	75	59
200	70	53.5	75	58.5	74	57.5	75	58.5
250	70	52.5	73	55.5	76	58.5	80	62.5
320	69	50.5	71	52.5	73	54.5	76	57.5
400	68	48.5	69	49.5	71	51.5	72	52.5
500	69	48	68	47	71	50	72	51
630	65	43	68	46	70	48	71	49
800	63	40	67	44	70	47	71	48
1000	67	43	73	49	74	50	77	53
1250	67	42	72	47	74	49	76	51
1600	66	40	69	43	71	45	72	46
2000	65	38	69	42	70	43	72	45
2500	58	30	65	37	69	41	70	42
3200	57	28	61	32	65	36	67	38
4000	57	27	60	30	64	34	66	36
5000	50	19.5	55	24.5	58	27.5	61	30.5
6300	45	14	50	19	54	23	56	25
8000	43	12.5	47	15.5	52	20.5	54	22.5
10000	40	8	43	11	47	15	50	18
Overall SPL								
	0"	85		94		92		92
	3"	86		93.5		93		92
	6"	87.5		94		93		91
	8"	88		94		93		93
Average								
Overall SPL		86.8		93.9		92.8		92.5
Current (amps)								
Voltage		30.2		36.8		43.8		49.9
Back Pressure		.23		.27		.325		.36

# ALB Sea Test (with tank pressure)

Bank Gross Prod	SWP Level	SWP Level	SWP Level	SWP Level	SWP Level	SWP Level	SWP Level
1000	40	43	11	15	15	15	15
8000	43	46	12.2	22	22	22	22
6000	46	49	13	23	23	23	23
4000	49	52	20	24	24	24	24
2000	52	55	21	25	25	25	25
1000	55	58	22	26	26	26	26
1000	58	61	23	27	27	27	27
1200	61	64	24	28	28	28	28
1400	64	67	25	29	29	29	29
1600	67	70	26	30	30	30	30
1800	70	73	27	31	31	31	31
2000	73	76	28	32	32	32	32
2200	76	79	29	33	33	33	33
2400	79	82	30	34	34	34	34
2600	82	85	31	35	35	35	35
2800	85	88	32	36	36	36	36
3000	88	91	33	37	37	37	37
3200	91	94	34	38	38	38	38
3400	94	97	35	39	39	39	39
3600	97	100	36	40	40	40	40
3800	100	103	37	41	41	41	41
4000	103	106	38	42	42	42	42
4200	106	109	39	43	43	43	43
4400	109	112	40	44	44	44	44
4600	112	115	41	45	45	45	45
4800	115	118	42	46	46	46	46
5000	118	121	43	47	47	47	47
5200	121	124	44	48	48	48	48
5400	124	127	45	49	49	49	49
5600	127	130	46	50	50	50	50
5800	130	133	47	51	51	51	51
6000	133	136	48	52	52	52	52
6200	136	139	49	53	53	53	53
6400	139	142	50	54	54	54	54
6600	142	145	51	55	55	55	55
6800	145	148	52	56	56	56	56
7000	148	151	53	57	57	57	57
7200	151	154	54	58	58	58	58
7400	154	157	55	59	59	59	59
7600	157	160	56	60	60	60	60
7800	160	163	57	61	61	61	61
8000	163	166	58	62	62	62	62
8200	166	169	59	63	63	63	63
8400	169	172	60	64	64	64	64
8600	172	175	61	65	65	65	65
8800	175	178	62	66	66	66	66
9000	178	181	63	67	67	67	67
9200	181	184	64	68	68	68	68
9400	184	187	65	69	69	69	69
9600	187	190	66	70	70	70	70
9800	190	193	67	71	71	71	71
10000	193	196	68	72	72	72	72

Bank Gross Prod	SWP Level	SWP Level	SWP Level	SWP Level	SWP Level	SWP Level	SWP Level
1000	40	43	11	15	15	15	15
8000	43	46	12.2	22	22	22	22
6000	46	49	13	23	23	23	23
4000	49	52	20	24	24	24	24
2000	52	55	21	25	25	25	25
1000	55	58	22	26	26	26	26
1000	58	61	23	27	27	27	27
1200	61	64	24	28	28	28	28
1400	64	67	25	29	29	29	29
1600	67	70	26	30	30	30	30
1800	70	73	27	31	31	31	31
2000	73	76	28	32	32	32	32
2200	76	79	29	33	33	33	33
2400	79	82	30	34	34	34	34
2600	82	85	31	35	35	35	35
2800	85	88	32	36	36	36	36
3000	88	91	33	37	37	37	37
3200	91	94	34	38	38	38	38
3400	94	97	35	39	39	39	39
3600	97	100	36	40	40	40	40
3800	100	103	37	41	41	41	41
4000	103	106	38	42	42	42	42
4200	106	109	39	43	43	43	43
4400	109	112	40	44	44	44	44
4600	112	115	41	45	45	45	45
4800	115	118	42	46	46	46	46
5000	118	121	43	47	47	47	47
5200	121	124	44	48	48	48	48
5400	124	127	45	49	49	49	49
5600	127	130	46	50	50	50	50
5800	130	133	47	51	51	51	51
6000	133	136	48	52	52	52	52
6200	136	139	49	53	53	53	53
6400	139	142	50	54	54	54	54
6600	142	145	51	55	55	55	55
6800	145	148	52	56	56	56	56
7000	148	151	53	57	57	57	57
7200	151	154	54	58	58	58	58
7400	154	157	55	59	59	59	59
7600	157	160	56	60	60	60	60
7800	160	163	57	61	61	61	61
8000	163	166	58	62	62	62	62
8200	166	169	59	63	63	63	63
8400	169	172	60	64	64	64	64
8600	172	175	61	65	65	65	65
8800	175	178	62	66	66	66	66
9000	178	181	63	67	67	67	67
9200	181	184	64	68	68	68	68
9400	184	187	65	69	69	69	69
9600	187	190	66	70	70	70	70
9800	190	193	67	71	71	71	71
10000	193	196	68	72	72	72	72

$A1\frac{1}{2}$  Fan Test (With Back Pressure)

Band Center Freq	n = 2600		3000		3200		3450	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	77	64.5	83	75.5	99	86.5	85	72.5
125	78	63	82	67	84	69	79	64
160	75	59	77	61	79	63	78	62
200	74	57.5	76	59.5	77	60.5	76	59.5
250	85	67.5	78	60.5	79	61.5	81	63.5
320	80	61.5	79	60.5	82	63.5	81	62.5
400	74	54.5	76	56.5	79	59.5	86	66.5
500	73	52	74	53	76	55	79	58
630	71	49	74	52	75	53	77	55
800	72	49	74	51	76	53	79	56
1000	76	52	79	55	80	56	82	58
1250	76	51	80	55	80	55	82	57
1600	73	47	78	52	78	52	79	53
2000	72	45	76	49	77	50	79	52
2500	71	43	73	45	74	46	76	48
3200	68	39	71	42	73	44	74	45
4000	67	37	72	42	74	44	75	45
5000	62	31.5	67.5	37	70	39.5	73	42.5
6300	58	27	62	31	65	34	68	37
8000	55	23.5	60	28.5	62	30.5	64	32.5
10000	51	19	55	23	57	25	60	28
Overall SPL								
	0"	92		97		104		96
	3"	92		97		103		96
	6"	92		97		103		95.5
	8"	93		96		103		96.5
Average Overall SPL								
		92.4		96.8		103.2		96.0
Current (amps)								
		4.2		4.65		4.93		5.3
Voltage								
		50.0		60.0		65.5		73.0
Back Pressure								
		.38		.45		.49		.54



$A_{1\frac{1}{2}}$  Fan Test (With Back Pressure)

Band Center Freq.	n = 3800		4200		4400	
	SPL	Spec Level	SPL	Spec Level	SPL	Spec Level
100	88	75.5	80	67.5		
125	87	72	82	67		
160	79	63	79	63		
200	80	63.5	78	61.5		
250	81	63.5	82	64.5		
320	80	61.5	81	62.5		
400	84	64.5	84	64.5		
500	79	58	83	62		
630	78	56	80	58		
800	80	57	83	60		
1000	83	59	84	60		
1250	84	59	86	61		
1600	81	55	82	56		
2000	80	53	82	55		
2500	78	50	80	52		
3200	75	46	77	48		
4000	77	47	78	48		
5000	76	45.5	78	47.5		
6300	72	41	75	44		
8000	68	36.5	71	39.5		
10000	63	31	65.5	33.5		
<hr/>						
Overall SPL						
	0"	97	99	99.5		
	3"	98	99	99.5		
	6"	98	100	100		
	8"	99	100.5	100		
<hr/>						
Average Overall SPL		98.0	99.6	99.8		
<hr/>						
Current (amps)		5.82	6.38	6.65		
Voltage		84.5	95.0	102.0		
Back Pressure		.61	.66	.7		

(continued from page 97) *John Doe*

9. Effect of Reversing Fan Direction  $A\frac{1}{2}$ ,  $n = 3450$  RPMOctave-Band Analysis

Band Freq Range	Spec Level Corr	Amb	Forward Direction			Back Direction		
			SPL	SPL Corr.	Spec Level	SPL	SPL Corr	Spec Level
			for Amb			for Amb		
75 - 150	18.8	55	63	62.5	43.7	62	61	42.2
150 - 300	21.8	55	61.5	61	39.2	60	58.5	36.7
300 - 600	24.8	41	66	66	41.2	65	65	40.2
600 - 1200	27.8	38	60	60	32.2	61.5	61.5	33.7
1200 - 2400	30.8	34	62.5	62.5	31.7	66.5	66.5	35.7
2400 - 4800	33.8	22	59.5	59.5	25.7	58.5	58.5	24.7
4800 - 10 kc	37.2	20	54	54	16.8	52	52	14.8
Overall SPL	0"	82	94			95		
	3"	82	94			95		
	6"	82	95			95		
	8"	82	95			96		
Average Overall SPL		82	94.5			95.2		

8. Effect of Revealing the Direction of the Force

Cognitive-Behavioral Analysis

[illegible]

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C. CALCULATIONS1. Adapter Design

Circular to Square Cross-Section (Equal Areas)

$$\frac{\pi D^2}{4} = S^2$$

$$D = 21.1875" \quad S = 18.76"$$

D = Diameter in inches

S = Side of Square Section  
in inches2. Design of Exponential Horn

$$A = A_0 e^{mx}$$

x = Longitudinal Distance  
from throat

$$\frac{\text{Equiv. Circ. Circum.}}{\lambda} \geq 1$$

m = Flaring Constant

$$m = \frac{2\pi f_0}{c}$$

$$\lambda = \frac{c}{f_0}$$

 $f_0$  = Cutoff FrequencyLowest fan speed is  
1000 RPM

$$f_0 = \frac{\text{RPM}_{\text{fan}} \times N}{60}$$

7 Blades

N = Fan Blades (7)

$$f_0 \approx 100 \text{ cps}$$

c = Speed of Sound in Air =  
1128 fps

$$\lambda = 11.28 \text{ ft.}$$

 $A_0$  = Throat Area

A = Area at Station x

Equivalent Circular Circumference (C) = 11.28 Ft. = 125.36 In.

$$A_{\text{mouth}} = \frac{(C^2)}{4\pi} = 1451.0 \text{ In}^2 \text{ for Square Cross-Section}$$

$$S_{\text{mouth}} = 38.1 \text{ In.}$$

$$mc = 2\pi f_0$$

$$A_0 = 356.0 \text{ In}^2$$

$$m = \frac{2\pi \times 100}{1128} = 0.557$$

$$S_0 = 18.76 \text{ In.}$$

$$\frac{1451.0}{356.0} = e^{0.557 x} = 4.07$$

$$x = 2.52 \text{ Ft.}$$

(Length of Horn)

# CALCULATIONS

## 1. Motor Input

Output of Motor (from Section 1) = 100 hp

$$\frac{100 \text{ hp}}{0.95} = 105.26 \text{ hp}$$

2 = Output in hp

3 = 100% of Motor Output in hp

## 2. Output of Mechanical Drive

4 = Mechanical Drive from Motor

5 = Output Constant

$$6 = \frac{5 \times 4}{2}$$

7 = Output Frequency

$$8 = \frac{100 \times 6}{20}$$

9 = Two Blades (V)

10 = Speed of Motor in ft/min

11 = 100 ft/min

12 = Thrust Area

13 = Area of Section

14 = Output of Mechanical Drive (1) = 11.25 ft/min = 100.56 in

$$15 = \frac{100 \times 11.25}{20} = 562.5 \text{ in}^2$$

16 = 100 ft/min

$$17 = \frac{100 \times 11.25}{11.25} = 112.5$$

18 = 100 ft/min

(Length of Motor)

19 = 100 ft/min

$$20 = 100 \times 11.25$$

$$21 = 100 \times 11.25$$

$$\frac{100 \times 11.25}{100} = 11.25$$

2. Design of Exponential Horn (continued)

$$A = A_0 e^{mx}$$

$$A_0 = 356.0 \text{ in}^2$$

$$m = .557$$

$x(\text{ft})$	$A_0$	$e^{mx}$	$A_x$	$S_x(\text{in})$
0	356	1	356	18.76 (throat)
0.5	356	1.322	471	21.72
1	356	1.746	621	24.94
1.5	356	2.310	822	28.65
2	356	3.05	1087	32.98
2.52	356	4.07	1451	38.10 (mouth)

5. Derivation of Experimental Data (continued)

$$A = A_0 e^{-kt} \quad \ln A = \ln A_0 - kt$$

$$A_0 = 100.0 \text{ g} \quad k = 0.027$$

$x$ (cm)	$A$ (g)	$\ln A$	$t$ (min)
0	100.0	4.605	0
0.2	98.0	4.585	1.0
1	92.0	4.522	5.0
1.5	88.0	4.480	7.5
2	84.0	4.434	10.0
2.5	80.0	4.382	12.5
3.0	76.0	4.330	15.0

3. Horn Check

$$I = \frac{\bar{p}^2}{\rho c}$$

$c$  = Speed Sound in air, cm/sec

$\rho$  = Density of air, dynes/cm<sup>3</sup>

$\bar{p}$  = RMS Pressure, dynes/cm<sup>2</sup>

$$IL = 10 \log_{10} \frac{I}{10^{-16}}$$

$$SPL = 10 \log_{10} \frac{\bar{p}^2}{(0.0002)^2}$$

$$\Delta IL = IL_x - IL_{throat} = 10 \log_{10} \frac{\bar{p}_x^2}{\bar{p}_{throat}^2}$$

$$\Delta SPL = SPL_x - SPL_{throat} = 10 \log_{10} \frac{\bar{p}_x^2}{\bar{p}_{throat}^2} =$$

$$= \Delta SPL = \Delta IL$$

$$I = \frac{\pi}{A \times 930}$$

$\pi$  = Sound Power in watts

$A$  = Area in square feet

$$\Delta IL = 10 \log_{10} \frac{\frac{\pi}{A_x \times 930}}{\frac{\pi}{A_{throat} \times 930}} = 10 \log_{10} \frac{A_{throat}}{A_x}$$

$$\frac{A_{throat}}{A_x} = \frac{1}{e^{mx}} = e^{-mx}$$

$x$  = Axial distance in horn from throat, feet.

$$\Delta IL = 10 \log_{10}(e^{-mx}) = -10 mx \log_{10} e =$$

$$(-4.36) (0.557) (x) = \underline{-2.43x = \Delta IL = \Delta SPL}$$

This gives the theoretical variation of change in sound-pressure level from the horn throat with axial horn distance.

1. Flow Chart

$\rho = \text{fluid density in air, g/cm}^3$   
 $\rho = \text{density of air, g/cm}^3$   
 $\bar{u} = \text{mean velocity, cm/sec}$

$$I = \frac{P}{\rho}$$

$$I = 10 \log_{10} \frac{P}{10^{-12}}$$

$$I = 10 \log_{10} \frac{P}{(0.001)^2}$$

$$I = 10 \log_{10} \frac{P}{10^{-12}} = 10 \log_{10} \frac{P}{(0.001)^2}$$

$$I = 10 \log_{10} \frac{P}{10^{-12}} = 10 \log_{10} \frac{P}{(0.001)^2}$$

$$I = 10 \log_{10} \frac{P}{10^{-12}}$$

$\rho = \text{fluid density in water}$   
 $\rho = \text{density of water}$

$$I = \frac{P}{\rho}$$

$$I = 10 \log_{10} \frac{P}{10^{-12}} = 10 \log_{10} \frac{P}{(0.001)^2}$$

$$I = 10 \log_{10} \frac{P}{10^{-12}} = 10 \log_{10} \frac{P}{(0.001)^2}$$

$$I = 10 \log_{10} \frac{P}{10^{-12}} = 10 \log_{10} \frac{P}{(0.001)^2}$$

$$(0.001)^2 = 10^{-6}$$

This shows the theoretical variation of sound pressure level from the sound source with distance.

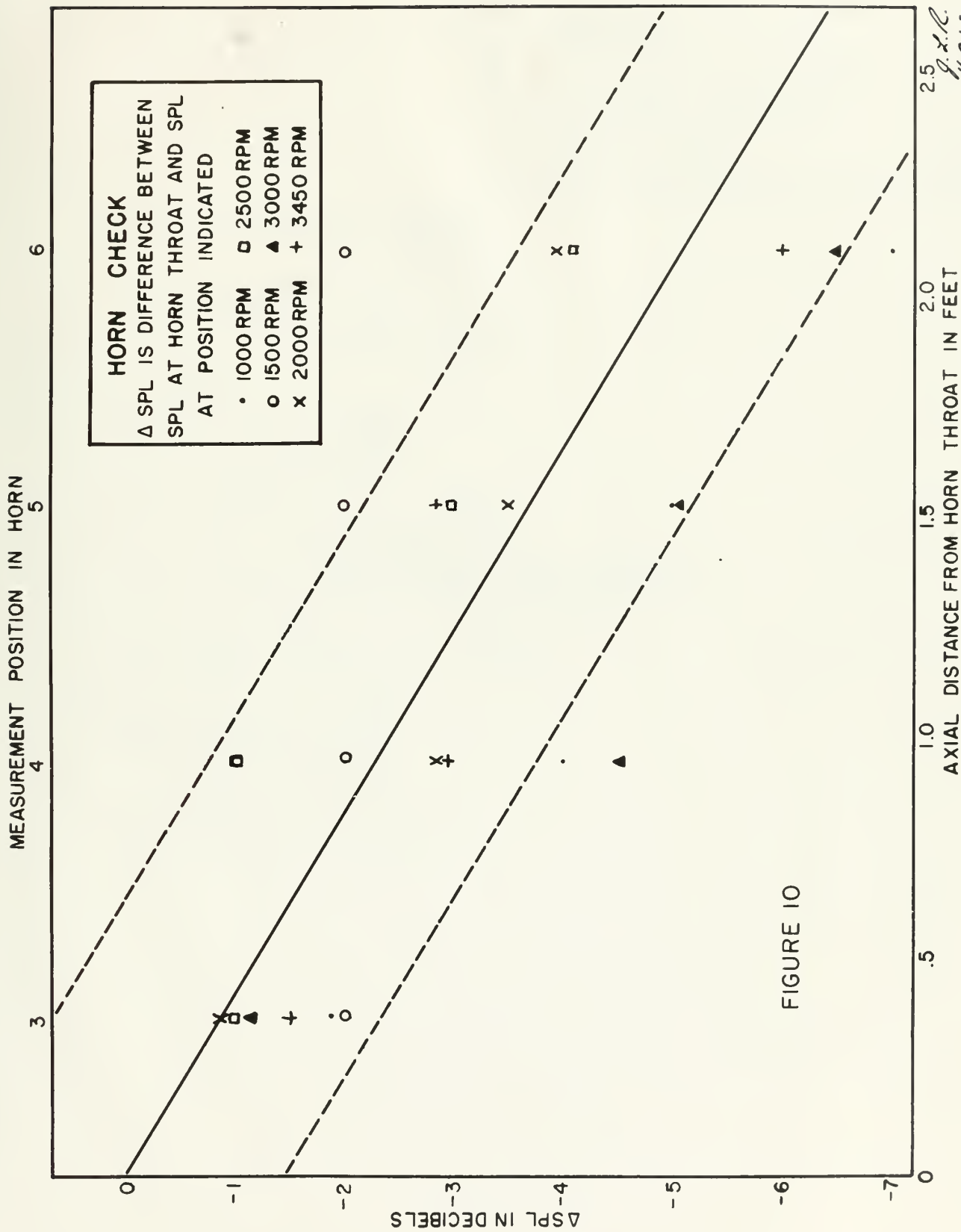


FIGURE 10

G. X. R.  
 K. E. W.  
 5/9/52



4. Conversion from SPL to PL in the Measuring Duct

SPL = Sound-pressure level in  
decibels

PL = Power level in decibels

I = Intensity, watts/cm<sup>2</sup>

π = Power, watts

A = Duct cross-section area in cm<sup>2</sup>

$$SPL = IL = 10 \log_{10} \frac{I}{10^{-16}}$$

$$PL = 10 \log_{10} \frac{\pi}{0.9 \times 10^{-13}}$$

$$\pi = IA$$

$$PL = 10 \log_{10} \frac{IA}{10^{-16}}$$

$$I = 10^{-16} \text{ anti-log}_{10} \frac{SPL}{10}$$

$$PL = 10 \log_{10} \frac{(10^{-16})(\text{anti-log}_{10} \frac{SPL}{10})(A)}{0.9 \times 10^{-13}}$$

$$PL = SPL + 10 \log_{10} A - 29.55$$

$$\text{Duct Diameter} = 21 \frac{1}{8}''$$

$$A = 2.25 \times 10^3 \text{ cm}^2$$

$$PL = SPL + 4.0 \text{ decibels}$$

$10^6 = 10^6 \times 10^6 = 10^{12}$   
 1000000

$10^3 = 10^3 \times 10^3 = 10^6$   
 1000

$10^3 = 10^3 \times 10^3 = 10^6$   
 1000

$10^3 = 10^3 \times 10^3 = 10^6$   
 1000

$10^3 = 10^3 \times 10^3 = 10^6$   
 1000

$$10^6 = 10^6 \times 10^6 = 10^{12}$$

$$10^3 = 10^3 \times 10^3 = 10^6$$

$$10^3 = 10^3$$

$$10^3 = 10^3 \times 10^3 = 10^6$$

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$$10^3 = 10^3 \times 10^3 = 10^6$$

$$10^3 = 10^3 \times 10^3 = 10^6$$

$$10^3 = 10^3 \times 10^3 = 10^6$$

5. Power Calculations

a. Resistance measurement from blocked rotor test

$$I = 0.4 \text{ amps}$$

$$V = 0.7 \text{ volts}$$

$$r_2 + r_s = \frac{0.7}{0.4} = 1.75 \text{ ohms} = R_a + s =$$

Resistance of armature plus series field

b. HP calculation - Assume motor windage losses  
and stray losses = 0

$$HP = \frac{1}{746} (IV - I^2 R_a + s)$$

n	I	V	VI	$I^2 R_{a+s}$	$A \frac{1}{2}$		
					HP calc	HP ~ $n^2$	HP ~ $n^2$
800	2.40	14.2	34	10.10	0.030	---	---
900	2.42	15.1	36.6	10.25	0.035	---	---
1000	2.43	16.9	41.0	10.33	0.041	---	---
1100	2.44	18.2	44.5	10.40	0.046	---	---
1200	2.55	19.5	49.7	11.38	0.051	---	---
1300	2.60	21.0	54.5	11.81	0.057	---	---
1500	2.78	24.3	67.5	13.02	0.073	0.073	0.027
1700	2.90	27.9	80.9	14.70	0.089	0.092	0.033
2000	3.05	33.3	101.5	16.30	0.114	0.128	0.046
2300	3.40	39.9	135.7	20.20	0.155	0.170	0.062
2500	3.55	45.9	162.8	22.00	0.189	0.200	0.073
2600	3.76	48.8	183.4	24.10	0.224	0.216	0.079
3000	4.04	55.0	222.0	28.40	0.259	0.289	0.105
3200	4.25	60.0	255.0	31.60	0.299	0.329	0.120
3450	4.60	70.0	322.0	37.00	0.382	0.382	0.140
3800	5.00	78.0	390.0	43.80	0.465	0.464	---
4200	5.60	90.0	504.0	54.90	0.600	0.566	---
4600	6.10	104.0	635.0	65.10	0.762	0.680	---

$$HP A \frac{1}{2} = \frac{0.4}{1.1} \times 0.382 = 0.140$$

at rated speed and no back pressure



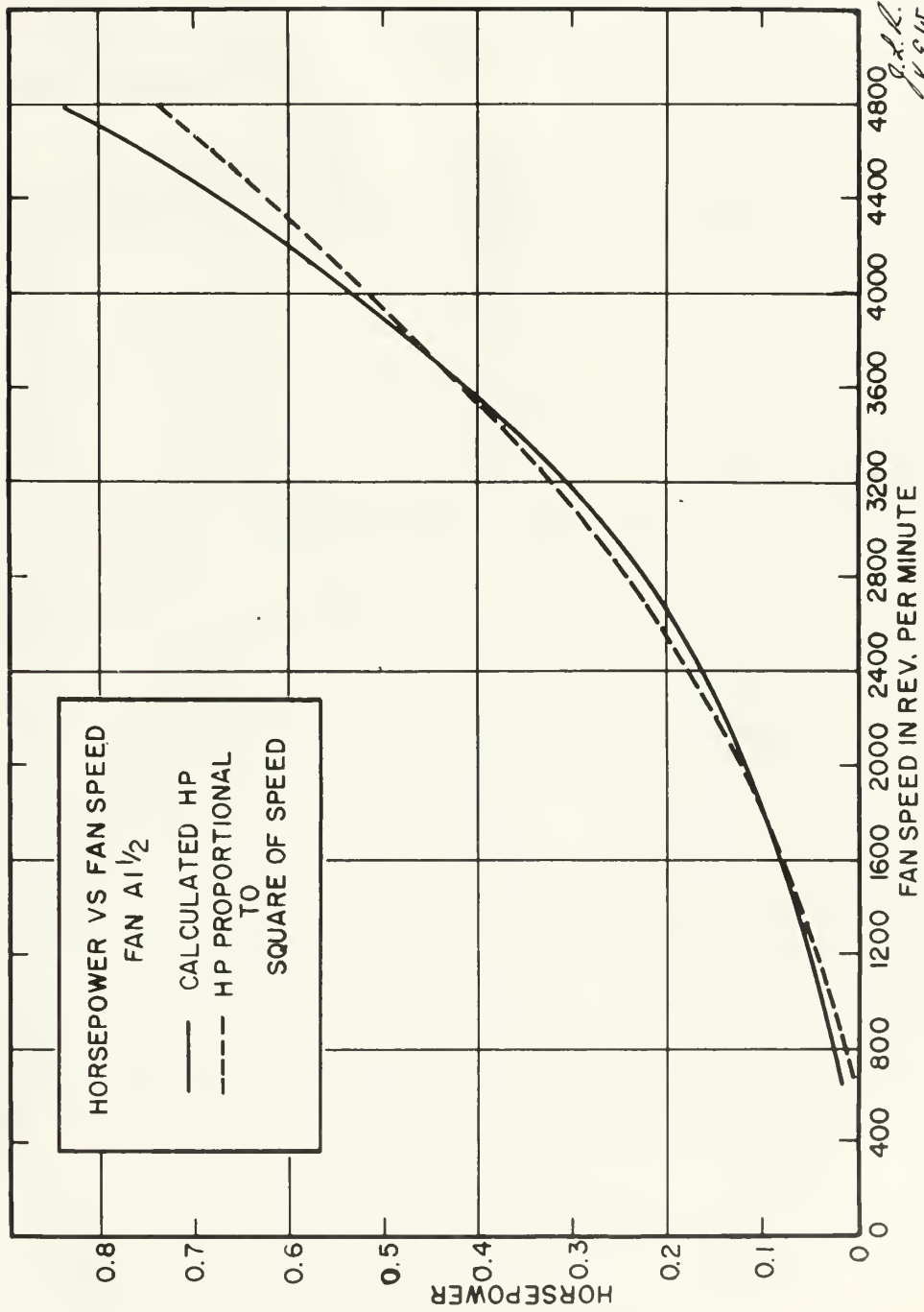


FIGURE 11

*G. L. L.*  
*K. E. W.*  
 5/9/52



6. Calculated Curves Based on

$$PL = 121.5 + 3.0 \log_{10} \frac{HP/Blade}{200} - \frac{34800}{n}$$

$A\frac{1}{2}$  (No Back Pressure)

n	HP	$3.0 \log \frac{HP/Blade}{200}$	$\frac{34800}{n}$	PL
2000	.047	-13.4	17.4	91.3
2300	.062	-13.1	15.2	93.7
2600	.080	-12.7	13.4	95.9
3000	.105	-12.4	11.6	98.0
3200	.120	-12.2	10.9	98.9
3450	.140	-12.0	10.1	99.9

$A1\frac{1}{2}$  (No Back Pressure)

2000	.128	-12.1	17.4	92.5
2300	.170	-11.7	15.2	95.1
2600	.216	-11.4	13.4	97.2
3000	.289	-11.1	11.6	99.3
3200	.329	-10.9	10.9	100.2
3450	.382	-10.7	10.1	101.2
3800	.464	-10.4	9.2	102.4
4200	.566	-10.2	8.3	103.5
4600	.621	- 9.9	7.6	104.5

c. Calculated Curves based on

$$P_L = 121.2 + 3.0 \log \frac{W/\Delta \rho}{h}$$

$\frac{1}{h^2}$  (No Back Pressure)

$P_L$	$\frac{W/\Delta \rho}{h}$	$h$
31.7	17.4	-13.4
33.7	15.2	-13.1
35.2	13.4	-12.7
38.0	11.6	-12.4
38.2	10.9	-12.5
39.2	10.1	-12.6

$\frac{1}{h^2}$  (No Back Pressure)

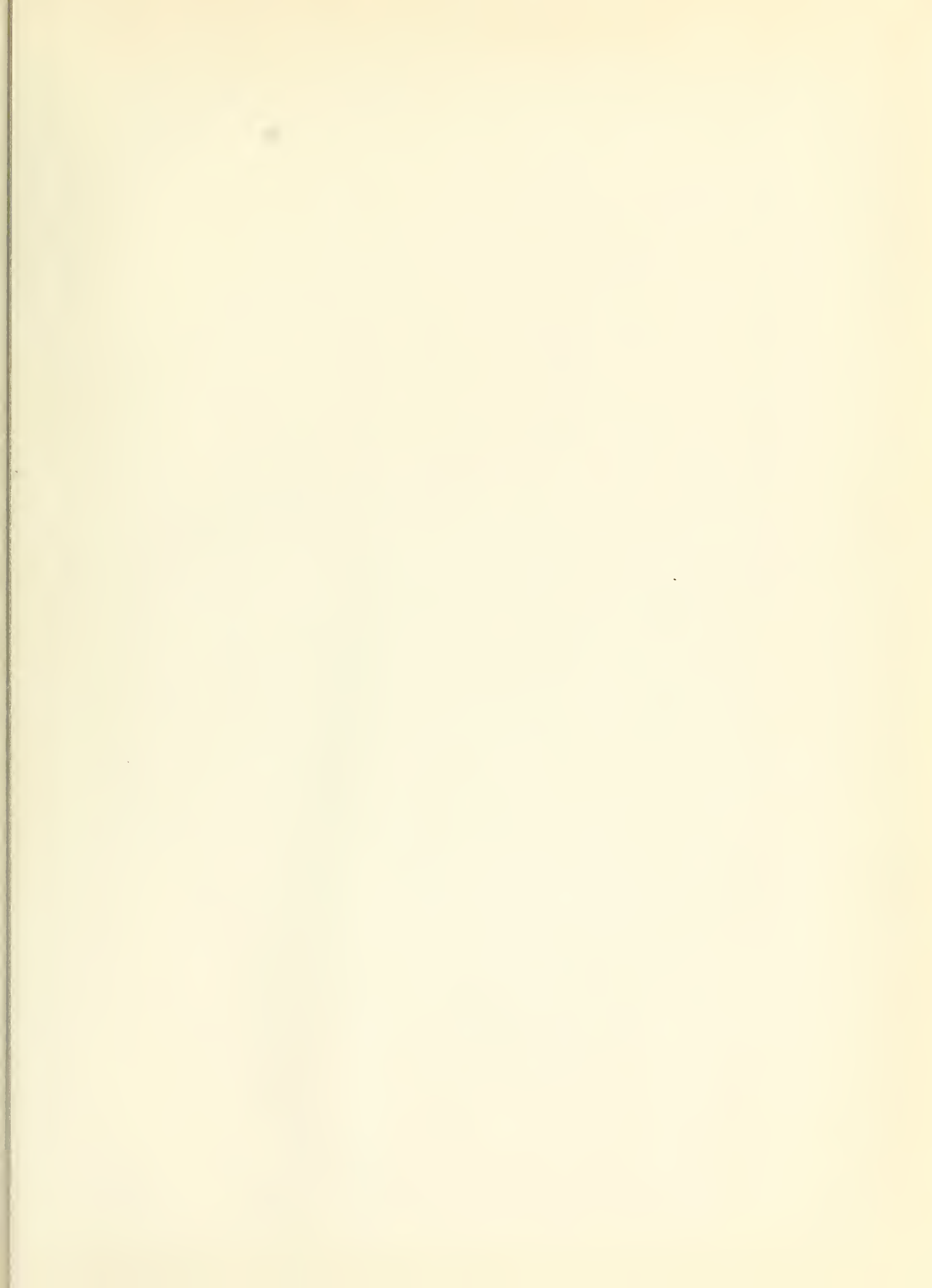
46.00	.621	-3.2
45.00	.566	-10.5
38.00	.464	-10.6
34.50	.382	-10.7
32.00	.323	-10.8
30.00	.289	-11.1
26.00	.216	-11.4
23.00	.170	-11.7
20.00	.138	-12.1

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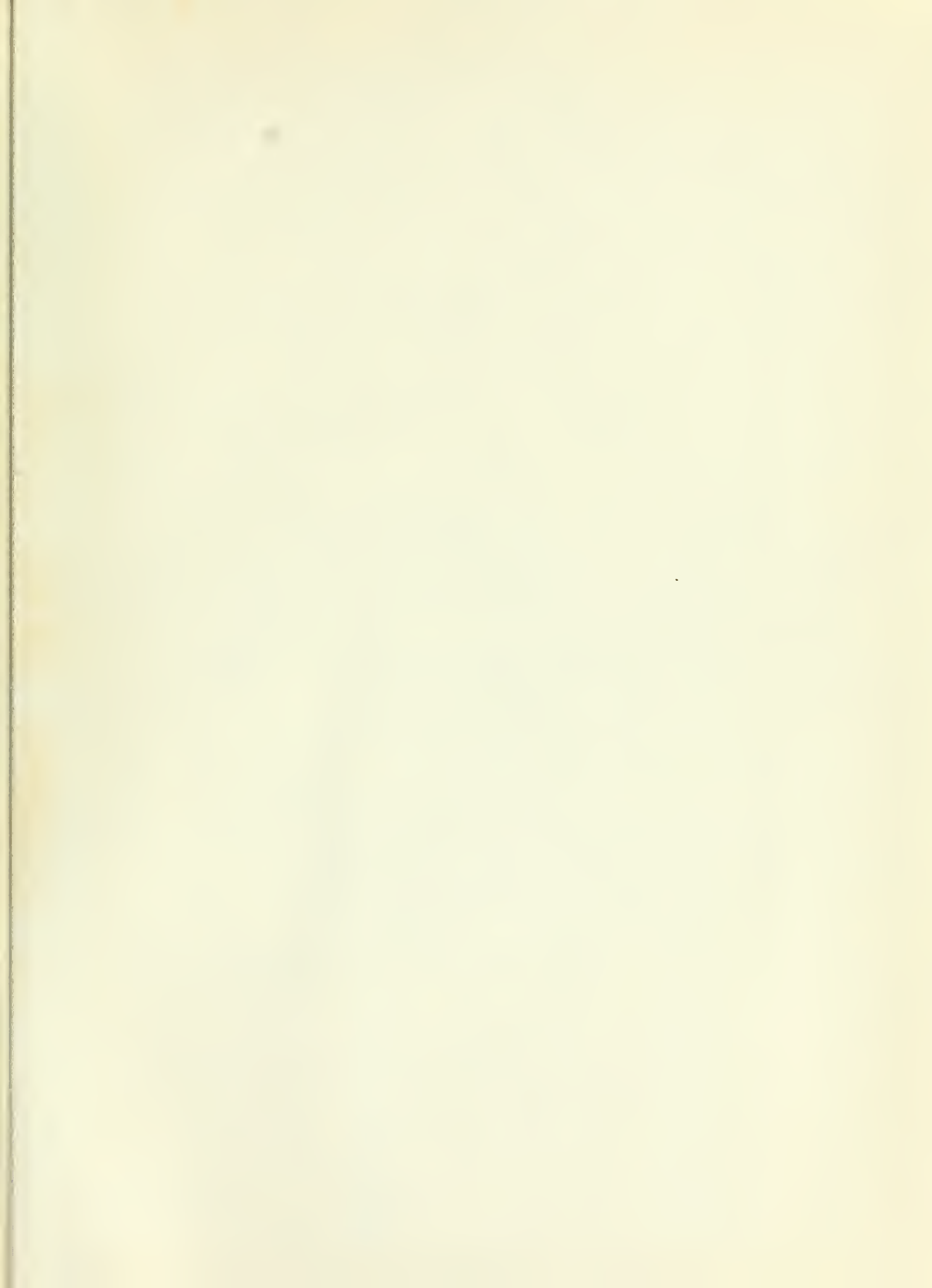
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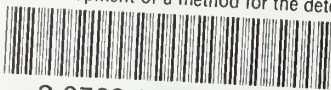
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